A MANUAL OF ELEMENTARY SCIENCE

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A COURSE OF WORK IN
PHYSICS, CHEMISTRY, AND ASTRONOMY
FOR QUEEN'S SCHOLARSHIP CANDIDATES

BY

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London
MACMILLAN AND CO., LIMITED
NEW YORK: THE MACMILLAN COMPANY
1901

GLASGOW: PRINTED AT THE UNIVERSITY PRESS
BY ROBERT MACLEHOSE AND CO.

PREFACE.

In the preparation of this volume two objects have been borne in mind, namely, (1) to construct a connected course of practical work and mental study suitable for pupil teachers taking elementary science with the view of presenting themselves in that subject at the Queen's Scholarship examination, (2) to provide a repertory of experiments illustrative of the fundamental principles of physical science, and capable of being performed with simple apparatus by students and teachers unfamiliar with laboratory methods.

Each chapter is divided into numbered sections corresponding to definite ideas, various aspects of which are first illustrated by experiment, and then dealt with descriptively. The experiments are complete in themselves; so are the descriptions of the principles involved, and this because it is not expected that every student will require, or be able, to carry out all the practical work. To some students, many of the experiments will be familiar, and they can refresh their memories by reading the descriptive text without repeating the laboratory exercises. Others may occasionally be compelled to postpone parts of the experimental work to a more convenient season, and they will find it an advantage to be able to follow intelligently the explanations referring to the principles exemplified by the omitted experiments.

With few exceptions the statements in the descriptive text can be justified by experiments preceding it. This is the scientific method—to show that the principles, rules, and relationships constituting natural knowledge are records of experience and not merely matters of opinion. Where experiments are not given, it is because the subject does not lend itself to practical illustration with simple apparatus.

Even in the astronomical chapters the plan of making practical work the grounds of belief for the subsequent descriptions has been followed. Attention is particularly invited to this fact, for, so far as we are aware, no attempt has previously been made in a book of this kind to show that elementary astronomy can be taught by the inductive methods adopted for instruction in physics and chemistry. It is not always possible or convenient to observe the heavenly bodies, but a good calendar or almanac contains tables showing their positions, apparent sizes, and other characteristics throughout

the year, and, with such a help, celestial objects can be followed day by day without actually observing them. The student who has merely read that the apparent path of the sun among the stars is called the ecliptic, can have no real conception of what the ecliptic is, but if he looks up the position of the sun in the heavens at intervals of a month or so as tabulated in an almanac, and plots these positions graphically, he will at once obtain an intelligent idea of the sun's apparent annual motion. So with all other phenomena of observational astronomy:—observation of the sky, and rough measurements of the positions of conspicuous bodies upon it, are of prime importance, but all the records thus obtained can be readily comprehended by connecting them with graphic exercises founded upon the facts given in almanacs.

The numerous new and original illustrations in the astronomical part of the book have been inserted with the intention of simplifying a subject which presents many difficulties to beginners. For, whatever may be said of other subjects, in astronomy illustrations are essential aids to study. Many new woodcuts will be observed in other parts of the book, and for the care he has bestowed on them Mr. O. L. Lacour merits our best thanks. We are also indebted to Messrs. Macmillan and Co., Ltd., for permission to use several illustrations from books published by them.

A few of the sections in some of the chapters on Physics and Chemistry have been adapted from *Elementary General Science*, Mr. Lionel M. Jones, one of the authors of that book, having kindly consented to this being done. We are glad to express our thanks for this favour.

One other point to which we desire to direct attention is the novel character of many of the questions at the ends of the chapters. It is fashionable to suggest that such questions encourage cram, but our opinion is that if a student merely took the questions one by one and found out for himself, by experiment or reading, the correct answers to them, he would be following the "heuristic" method almost as closely as if he undertook an investigation of the constitution of a piece of chalk. When the questions are not original the source is stated, the papers from which selections have been made being those set at examinations for the London Matriculation, Oxford and Cambridge Locals, Queen's Scholarship, Pupil Teachers, London Technical Education Board, and South Kensington. Questions from the Physiography papers of the last-named examining body have merely the number of the year in which they appeared printed after them.

R. A. GREGORY.
A. T. SIMMONS.

LONDON, *January*, 1901.

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CHAPTER I.

FORMS OF MATTER.

Matter.—Every person is being continually brought by means of his senses into contact with things of all kinds. These objects, substances, stuffs, or whatever they may be called, become known in different ways, appealing as they do to different senses. Some are smelt, some are seen, others are felt, while others again become known by the powers of tasting and hearing. But by whichever of the five gateways of knowledge—as the senses have been called—the information reaches the brain, the result is an acquaintance with *material* things, or, as they may also be called, *forms of matter*, in the universe. The general term used to speak of all kinds of material things is *matter*, which may be defined as *all things existing in or out of our world, which we become aware of by the help of our senses.*

It is worth while to bear in mind that all facts of science are examined by the help of the senses. When, therefore, any information is gained by an accurate use of the carefully trained senses, it may be regarded as a fact of science. Or, to use an expression of Huxley's, "science is organised common sense."

Different kinds of matter.—Though matter exists in an infinite variety of forms, living and dead, the different kinds may be arranged roughly into three classes, according to certain of the properties they possess. These classes are:

(1) Solid things or solids;
(2) Liquid things or liquids;
(3) Gaseous things or gases.

Sometimes the last two are made into one class and called *fluids.*

There is no hard and fast line dividing one state of matter from another. There is, in fact, a gradual transition from the solid condition to the gaseous state; while gases themselves may be made so attenuated that they lose the properties possessed by them under ordinary conditions and exist in a state of what is known as *radiant matter*.

As everybody knows, some solids are much softer than others; yet, however soft a material thing may be, if it has no power of *flowing*, it must be regarded as a solid. Thus, cold jelly is a solid because it will not flow, a fact which can be demonstrated by placing a very small weight, such as a mustard seed, upon it. The slight depression which the seed causes does not increase with the lapse of time, hence there is no flow. Sealing wax, on the contrary, is a fluid because of its power of slowly flowing. If a stick of sealing wax is supported horizontally between two needle points it is found, after a time, to have taken up a curved form, as one particle of the wax has moved over the other.

In a similar manner a gradation can be traced in liquids themselves. Treacle and tar flow much less readily than water and alcohol; or, as it may be otherwise expressed, water and alcohol are much more *mobile* than treacle and tar; or treacle and tar are much more *viscous* than water and alcohol.

But it must not be forgotten that gases as well as liquids have the power of flowing; they as well as liquids are known as fluids. This interesting question of the classification of the forms of matter might be indefinitely extended, but it will here be sufficient to call attention to this gradation of properties, and to again remind the reader that the division of the forms of matter into solids, liquids, and gases is a very rough one.

There are, however, certain broad distinctions between these three classes of matter with which the student must make himself familiar, and, as in all questions of physical science, this is only to be done satisfactorily by means of experiment. We shall first give a series of simple practical exercises on these distinctive properties, and afterwards proceed to deal with the principles exemplified by the experiments.

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1. SOLIDS, LIQUIDS, AND GASES.

i. All forms of matter have a certain size.—(*a*) This is really a piece of common knowledge. Examine several solid things. Notice

that though moved from one place to another the amount of room they occupy, or their sizes, remain unaltered.

(*b*) *Fill* a wine-glass with water. Pour the water from one vessel to another of a different shape, and finally pour the water back into the wine-glass again. Notice the glass is again filled, or the size of the water remains unaltered.

(*c*) Think about the question and satisfy yourself that at any particular moment a quantity of gas, since it fills the containing vessel, has a certain size.

ii. **All forms of matter offer resistance.**—(*a*) To remind yourself of the truth of this as regards solids, try to push any solid thing out of its place, or to push a finger through a sheet of cardboard. Resistance is offered in each case.

(*b*) Draw your hand through water in a trough, and in this way recall the resistance offered by water.

(*c*) Wave a book or drawing-board about in the air. The resistance of the air is enough to demonstrate the resistance offered by gases.

iii. **All forms of matter possess weight.**—(*a*) Lift a book or a weight from a table; the effort required to lift it measures its weight.

(*b*) Similarly lift an empty bottle from the table, and immediately after lift the same bottle filled with water; you will have no difficulty in recognising that the liquid possesses weight.

(*c*) It is advisable to postpone the experimental proof of the same fact in the case of gases until the use of the balance has been learnt.

iv. **Shapes of solids, liquids, and gases.**—(*a*) Put a stone into a teacup, then into a tumbler, and then into a basin; the shape of the stone remains the same wherever it is placed. Also examine a solid on two succeeding days; notice its shape has not altered.

(*b*) By pouring the same amount of water into different vessels, convince yourself that the shape of the water depends upon the shape of the lower part of the containing vessel.

(*c*) Refer to Experiment 1, v. (*c*), and notice that it also shows that the shape of a gas is that of the vessel containing it, which it always completely fills.

v. **Free surface of solids, liquids, and gases.**—(*a*) Examine a number of solids, and observe that the free surface of the solid is determined by its shape. A wooden cube, for instance, always keeps its six faces if left to itself.

(*b*) Into a shallow vessel pour enough mercury to cover the bottom. With a ball of lead and a fine string construct a plumb line. Hang it above the mercury, and notice that the string and its reflection are in one and the same line. If this were not so, that is, if the image slanted away from the plumb line, we should know the surface of the liquid was not horizontal.

(*c*) Collect a bottle of ordinary gas in the following way. Fill a bottle with water, and invert it in a basin of water; then displace the liquid with gas led from a jet by a piece of indiarubber tubing (Fig. 1). Now insert a cork into the neck of the bottle while it is

still under water, and lift the bottle out of the water and place it on the table. The gas has the size and shape of the bottle.

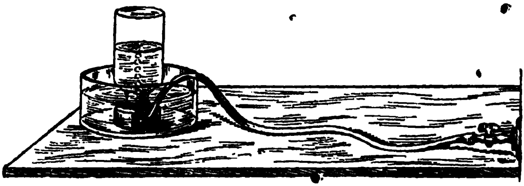

FIG. 1.—How to collect gas in a bottle.

Open the bottle and wave it about; you immediately notice the smell of gas throughout the room, and know from this that the gas is everywhere in the room, and therefore has the size and shape of the room.

Properties possessed by all forms of matter.—Matter, in whatever form it exists, always possesses certain characteristics known as "general properties." Whether in the state of a solid, liquid, or gas, matter must *occupy a certain space.* The larger a material body is the more space it occupies.

Matter, too, *offers resistance.* We become aware of this, in the case of solids, if we knock ourselves against the wall or the table. If we swim or wade in water we know the same thing is true of water, and so we find it to be of all liquids. If we attempt to run with a screen in front of us we become conscious of the resistance offered by the air to our onward progress, and from this argue that gases, too, offer resistance.

Matter always has weight.—Without knowing the full significance of the expression *weight*, the reader will have a sufficiently clear idea of what is meant by this property from its familiar use in everyday conversation. By lifting a solid we become conscious of its possession of this property; if we lift an empty bottle and then one full of any liquid, we shall find it is lighter in the first instance, or, as we say, the liquid has weight. By the exercise of sufficient care, in just the same manner it can be shown what gases have weight.

If we kick a football, or send a jet of water at a heap of dust or sand, or blow at a piece of paper, another of the general properties of matter can be demonstrated, namely, its power of giving motion to other things by striking against them. To sum up, "*Matter always occupies space, offers resistance,*

possesses weight, and transfers motion to other things when it strikes against them."

Solids.—Things which have a size and shape of their own, and remain of the same size and shape so long as they are not interfered with, are called *solids.* Some solids are harder than others, and some can have their shape altered more easily than others. But none of them change by themselves. In fact, *a solid body does not readily alter its size or shape. It keeps its own volume and the same form unless acted upon by a considerable force.*

Another way of expressing the chief facts contained in the definition is to say that *solids possess rigidity.* Because of their rigidity every solid has a definite free surface and a definite shape.

Liquids.—If a wine-glassful of water is poured into a tumbler the water fills the lower part of the tumbler. Originally the water had the shape of the wine-glass, but after the transfer it takes the shape of the lower part of the tumbler. And, if it be poured successively into vessels of different shapes, the water always assumes the shape of the lower part of the containing vessel. Throughout all the changes of shape there is no alteration of size; for if at the end of the experiment the water is poured back into the wine-glass it exactly fills it.

The surface of a liquid at rest is always horizontal if the vessel containing it is not very small. This is one of the results of the fluidity, or power of flowing, possessed by liquids in common with gases. When not held by the sides of the containing vessel a liquid at once flows.

These facts provide a definition which includes all the important characters of liquids. *A liquid at rest has a horizontal surface and takes the shape of the part of the vessel below the surface, but the conditions remaining the same, the liquid keeps its own size or volume, however much its shape may vary.*

Not only is the power of flowing possessed by fluids, but also by some powders. Fine sand may be made to flow, but the particles do not move freely over one another, so the surface is left uneven. Indeed the horizontal surface of liquids at rest provides a clear means of distinguishing between a solid and a liquid.

Gases.—A liquid always adapts itself to the shape of the containing vessel, and presents a level surface at the top; a gas, on

the other hand, will, however small its volume, immediately spread out and do its best to fill the vessel, however large; and it does not present any surface to the surrounding air. We can never say exactly where the gas leaves off and the air begins.

Gases possess fluidity to a much more marked degree than liquids. Liquids and gases are, as has been seen, both classified as fluids. But, whereas liquids are almost incompressible, gases are very easily compressed into a much smaller space; their chief characteristics can be stated thus: *Gases are easily compressible and expand indefinitely.*

Another distinction between liquids and gases will be more fully appreciated after the action of heat upon the volumes of bodies has been studied. All bodies get larger as they are heated, but this is much more decidedly the case with gases than with liquids. Gases, moreover, expand equally when heated to the same extent. All these facts will, however, be better understood in their proper places.

---

2. THE SAME KIND OF MATTER CAN EXIST IN DIFFERENT STATES.

i. Ice, water, and steam are different forms of the same kind of matter.—(*a*) Procure a lump of ice and notice that it is a solid, or has a particular shape of its own, which, as long as the day is sufficiently cold, remains fixed.

(*b*) With a sharp bradawl, or the point of a knife, break the lump of ice into pieces, and put a convenient quantity of them into a beaker. Place the beaker in a warm room, or apply heat from a laboratory burner or spirit lamp. The ice disappears, and its place is taken by what we call water. Notice the characters of the water are those of a liquid. It has no definite shape, for by tilting the beaker the water can be made to flow about.

(*c*) Replace the beaker over the burner and go on warming it. Soon the water boils, and is converted into vapour, which spreads itself throughout the air in the room, and seems to disappear. The vapour can be made visible by blowing cold air at it, when it becomes white and visible, but is really no longer vapour, for it has condensed into small drops of water.

ii. Some metals assume the liquid condition when heated.—Heat a piece of lead or zinc in an iron spoon. Observe the solid metal eventually changes into a liquid, and that more heating is required to effect the change than in the case of ice.

iii. Sudden change from solid to gaseous state.—Warm a dry flask

by twirling it between the finger and thumb above the flame of a laboratory burner. When it is too warm to bear the finger upon the bottom, introduce a crystal of iodine, and notice it is at once converted into a beautiful violet vapour. Notice the formation of crystals on the inside of the flask as the vapour cools.

iv. **Sublimation.**—Gently heat a few crystals of sal-ammoniac (ammonium chloride) in a dry test tube. Notice the rapid conversion of the solid into a vapour, and the deposition on the cold upper part of the tube of a white solid as the vapour cools.

v. **Gradual change of state.**—Warm a lump of sealing wax, or bicycle cement, in an iron spoon, and notice the gradual conversion into a liquid.

Changes of state in same kind of matter.—To the fact that there are three kinds of material things, we must add another idea, viz., that the *same matter can exist in all three forms.* The change in the state of matter, whether from the solid to the liquid condition, or from the liquid form to the gaseous state, is most easily brought about by heat. Reverse changes, viz., from gas to liquid and from liquid to solid, can be effected by cooling.

The degree of heating required to bring about the above changes varies very greatly with different substances. Iron must be heated very much more than ice before it can become a liquid. Alcohol, again, has to be cooled to a much greater extent than water before the liquid condition gives place to that of a solid.

When a substance has, as a result of heating, successively passed through the solid, liquid, and gaseous states, then, if the conditions are reversed and the gas is continuously cooled, the liquid form is first reassumed, and subsequent cooling causes the liquid to change again into the original solid.

Sudden and gradual changes.—The circumstances attending the change from the solid to the liquid, or from the liquid to the gaseous state, are not always the same as in the case of water. When a crystal of iodine is heated, it appears to suddenly pass from the condition of a solid to that of gas. Camphor is another instance of this sudden transition from solid to vapour. When, on the other hand, sealing-wax is heated, it very gradually passes into the liquid condition, and may be obtained in a kind of transition stage—neither true solid nor true liquid.

3. NO LOSS OF MATTER DURING CHANGE OF STATE.

i. **No loss of matter during melting.**—(*a*) Place a piece of ice in a flask suspended from a spring balance. Notice the weight indicated; then melt the ice by warming the flask, and observe that the weight of the water is practically the same as that of the ice.

(*b*) Suspend from a spring balance a test-tube containing a little butter or wax. Notice the weight. Melt the butter or wax, and observe that there is no change of weight.

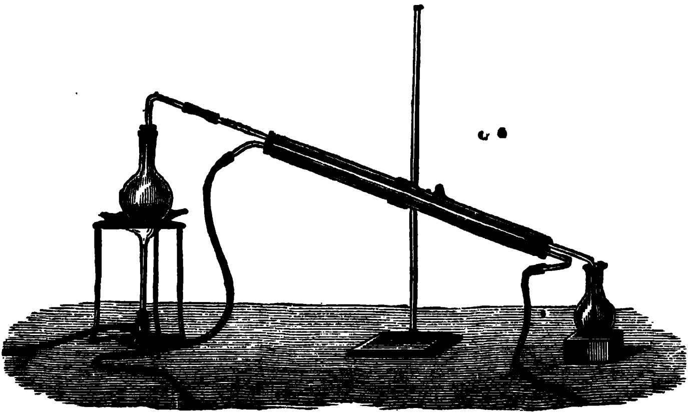

FIG. 2.—Conversion of water into steam and steam into water.

ii. **No loss of matter during vaporisation.**—(*a*) Boil water gently in a flask fitted like that in Fig. 2. The steam passes through a tube surrounded by a wider tube in which cold water is kept flowing. Catch the condensed steam in a flask placed at the lower end of the inside tube. If none of the steam is permitted to escape, the water thus collected will be found to have the same mass as that boiled away.

(*b*) Place a few crystals of iodine in a flask, and cork them up tightly. Suspend the flask from a spring balance and notice the weight. Heat the flask; the iodine is partly converted into a vapour or gas, but the weight remains the same.

iii. **No loss of matter accompanies solution.**—Put some water in a small flask, and a little salt in a piece of paper. Counterpoise the flask of water and the paper of salt together, and then dissolve the salt in the water. The total weight remains unaltered.

Change of state does not imply change of weight.—At first sight it would seem that when the state of a substance is changed its weight also undergoes alteration. This, however, is not the case. If 1 lb. of ice is melted, 1 lb. of water is produced, and if the lb. of water is converted into steam, there is still only 1 lb. of vapour, provided that care is taken not to let any escape. This constancy in the weight of the water, whether in a solid, liquid, or gaseous state, applies equally to all substances. Similarly, solution takes place without any loss of weight. It will be seen in later chapters that even when the original substance entirely disappears there is no actual loss of weight.

CHIEF POINTS OF CHAPTER I.

The word **matter**, in science, means any material, substance, stuff, or thing.

Forms of matter.—(1) Solids, (2) Liquids, (3) Gases. Fluids include both liquids and gases. *Mobile* fluids flow easily; *viscous* fluids flow slowly.

A solid has a definite weight, volume, shape, and surface, which remain the same under the same conditions.

A liquid at rest has a definite weight and volume, but its shape is that of the vessel containing it up to the surface, which is horizontal.

A gas has a definite weight and a definite volume under constant conditions, but it has no definite shape or surface.

TABLE OF PROPERTIES.

	Solid.	Liquid.	Gas.
Weight.	Definite.	Definite.	Definite.
Volume.	Definite.	Definite.	That of containing vessel.
Shape.	Definite.	Indefinite.	Indefinite.
Free Surface.	Definite.	Horizontal.	Indefinite.

Change of state.—Many solids change into liquids when sufficiently heated, and these liquids may be converted into gases if the heating is continued. Water can be obtained in the three states of solid, liquid, and vapour, or gas.

Constancy of weight.—There is no change of weight when a certain quantity of a solid, liquid, or gas has its state altered by heating or cooling it.

EXERCISES ON CHAPTER I.

1. What are the three forms of matter, and what are their distinctive features? Give two examples of kinds of matter of which all the three forms are known to you, and state the conditions under which they exhibit the different forms. (1899.)

2. In what respects are liquids different from solids? And how do they differ from gases?

3. What properties are usually associated with matter in the solid form? Write a definition of a solid which includes the chief of these properties.

4. It has been said that there is no hard and fast line dividing one form of matter from another. State as many facts as you are able in support of this assertion.

5. How would you show to a class of children that there is no loss of mass when (*a*) a lump of ice changes into water, (*b*) when a quantity of sugar is dissolved in water, (*c*) when some water is changed into steam?

6. Compare the surfaces of solids, liquids, and gases in a state of rest. What experiments could be performed in support of your statements?

CHAPTER II.

MEASUREMENT OF SPACE, MASS, WEIGHT, DENSITY.

4. LENGTH. AREA. VOLUME.

i. Units of Length.—(*a*) Procure a rule divided into inches and parts of an inch on one edge, and metric measures on the other, as in Fig. 3. The smallest divisions upon the metric scale are *millimetres* (*mm.*), 10 of these millimetres make 1 *centimetre* (*cm.*), 10 centimetres make a *decimetre* (*dm.*), and 10 decimetres make 1 *metre*. A metre thus contains 10 decimetres, 100 centimetres, and 1000 millimetres.

Find how many millimetres there are in the length of this page. Write down the result in (1) millimetres, (2) centimetres and tenths of a centimetre, (3) decimetre and tenths and hundredths of a decimetre.

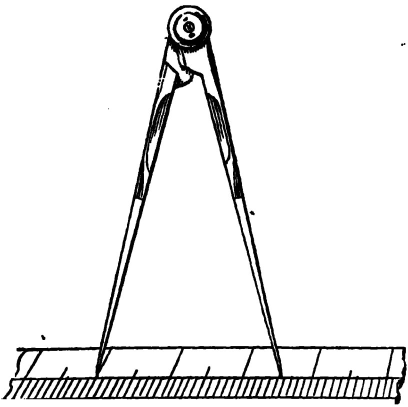

FIG. 4.—The points of the dividers are separated by 1 inch. There are 25·4 millimetres in this length.

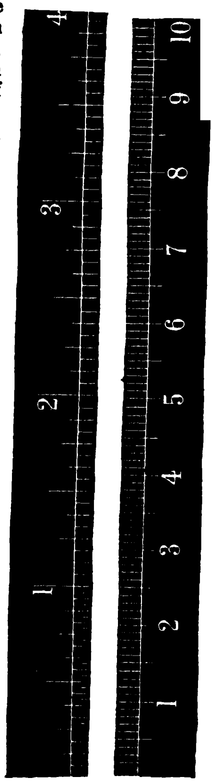

FIG. 3.—10 centimetres = 100 millimetres = length of about 4 inches.

(*b*) Carefully open a pair of dividers until the points are exactly an inch apart. Place the points upon a metric scale, and notice how many millimetres are included between them (Fig. 4).

(*c*) Find how many centimetres and tenths of a centimetre are equivalent to the length of one foot. Thence, calculate the number of centimetres in the length of an inch.

(*d*) Measure the length of this page both in inches and centimetres; also determine other lengths in the two systems of measurement.

Put down the results in parallel columns, as shown below, and from them calculate the number of centimetres in an inch.

Length in centimetres.	Length in inches.	$\frac{\text{No. of centimetres.}}{\text{No. of inches.}}$

(*e*) Measure the length of your desk, or of a table, or other convenient object, in inches and decimals (tenths) of an inch. Determine the same length in metres and decimals of a metre. Use the results to determine the number of inches in a metre.

ii. **Units of Area.**—(*a*) Draw a square inch and a square centimetre side by side (Fig. 5).

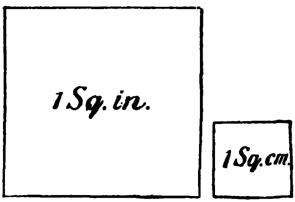

FIG. 5.—Comparative areas of 1 sq. in. and 1 sq. cm.

(*b*) Draw a square decimetre and divide it into square centimetres. The area of the square is thus shown graphically to be equal to the length multiplied by the height. Now draw two or three oblongs and determine their areas by means of this rule. Determine the areas of the square and oblongs both in square inches and square centimetres, and use your results to find the number of square centimetres in one square inch, thus:

Area of a given rectangle in square inches.	Area of same rectangle in square centimetres.	$\frac{\text{Square centimetres.}}{\text{Square inches.}}$

(*c*) Draw a square foot and a square decimetre and find the number of square decimetres in the square foot, and the fraction which one square decimetre is of one square foot.

iii. **Units of Volume.**—(*a*) Procure a box or a block one cubic foot in size. Divide the top and the other faces of the cube into square inches (Fig. 6). Notice that the area of each face of the cubic foot is one square foot. Count the number of square inches marked on one face. Notice that 144 cubic inches could be cut out of a slab of the cube one inch thick. How many slabs having a thickness of one inch could be cut from one cubic foot, and how many cubic inches are there altogether in such a cube?

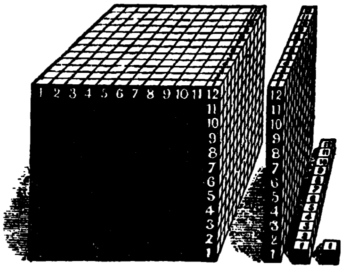

FIG. 6.—To explain why 1728 cubic inches make one cubic foot.

iv. **How to find the volume of a solid.**—(*a*) Obtain a jar graduated in cubic centimetres and fill it about three-quarters full of water. Observe the level of the water and then gently drop in the small solid, the volume of which is required. The rise of water-level which immediately takes place shows the volume of the solid in cubic centimetres.

(*b*) If the object is lighter than the liquid employed, a sinker made of lead or iron should be employed. First place the sinker in water and notice the level; then take the sinker out of the water and tie it with thread to the light object, and place them both in the jar. The additional rise of level which takes place will give the volume of the object.

Measurement of length.—Before comparing any one length with any other we must have some standard to which we can refer them. In this country the standard adopted is the length between two marks on a platinum bar kept at the Exchequer Chambers, the bar being at a certain fixed temperature when the measurement is made. This length is quite arbitrary and is called a *yard*. The yard is subdivided into three equal parts, each of which is a *foot*. The foot is in its turn divided into twelve equal parts, called *inches*. Multiples of the yard are also used and special names given to them, such as mile, furlong, etc.

French geometricians decided that such an arbitrary standard was, in view of the chance of its loss or destruction, an undesirable one, and suggested that if a fraction of the circumference of the earth were taken they would, in the event of the loss

of the standard, be easily able to replace it by an exact copy. They proposed the one tenth-millionth part of the distance from the earth's equator to the pole—that is, the earth's quadrant—as a suitable length, and this they called the *metre*. After bars had been prepared of this length it was unfortunately found that the length of the quadrant had not been exactly determined, and consequently the length of the standard metre at Paris is arbitrary, and we must define the standard metre as being the length at a certain temperature between two marks on a platinum bar kept at Paris. It is equal to 39·37079 inches. The metre is subdivided into ten equal parts, each of which is called a *decimetre*, the tenth part of the decimetre is called a *centimetre*, and the tenth part of the centimetre is known as a *millimetre*. Thus, we get

$$10 \text{ millimetres} = 1 \text{ centimetre}$$

$$\left.\begin{array}{r}10 \text{ centimetres}\\ 100 \text{ millimetres}\end{array}\right\} = 1 \text{ decimetre}$$

$$\left.\begin{array}{r}10 \text{ decimetres}\\ 100 \text{ centimetres}\\ 1000 \text{ millimetres}\end{array}\right\} = 1 \text{ metre}$$

The multiples of the metre are named *deka-*, *hekto-*, and *kilo-metres*. Their value is seen from the following table:

10 metres = 1 dekametre
100 metres = 1 hektometre
1000 metres = 1 kilometre

The kilometre is equal to about three-fifths of a mile.

Measurement of area.—In referring to the measures of area (or space of two dimensions) in the English system the same names are used as in measures of length; simply prefixing the word *square* indicates that areas are meant. Thus, we speak of square inches and square feet; and, since there are 12 linear inches in a linear foot there are $12 \times 12 = 144$ square inches in a square foot, and similarly throughout the measure. So, too, in the metric system it is the custom to speak of an area as of so many square centimetres, or square metres, as the case may be.

Measurement of volume.—The *volume* of a thing is its size, or bulk, expressed in proper units. In dealing with volumes, three dimensions have to be considered. Just as a plane surface or area measuring one foot in each of the directions, length and breadth, is called a square foot from the name of the figure which it forms, so a solid which is obtained by measuring

a foot in three directions, length, breadth, and thickness, is called a cubic foot, from the name *cube* given to the solid so formed. Similarly using the *Metric or Decimal* system, we may speak of a cubic metre, or a cubic decimetre.

A hollow vessel is capable of holding a certain volume, and this is usually referred to as the *capacity* of the vessel. In the metric system a special name is given to the capacity of a hollow cubic decimetre, that is, a hollow cube having a decimetre edge. It is called a *litre*, and is equal to about one and three-quarters English pints. The sub-multiples and multiples of a litre are named in a similar way to those of the metre. There is no such simple relation between the measures of length and volume in the English system, though the gallon is defined as a measure which shall contain 10 lbs. of pure water at a certain temperature and pressure.

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5. MASS AND ITS MEASUREMENT.

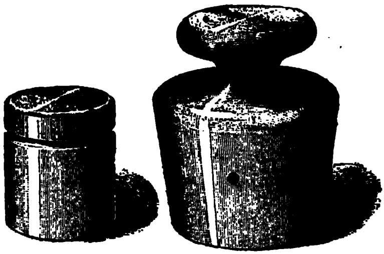
i. **Measurement of mass.**—(*a*) Take two pieces of iron or brass, called in ordinary language "pound" and "half-pound weights"; or a "pound" and a "two-pound" will do. Lift the two pieces of metal. One feels heavier than the other, that is, the masses are different.

(*b*) Examine examples of British masses, *e.g.* an ounce, a pound, a half-hundredweight. Also examine a box of metric masses, generally spoken of as a box of "weights."

(*c*) Compare a pound with a kilogram. Hang the 100-gram mass from a spring balance, and notice that the downward pull or its *weight* is equal to the weight of $3\frac{1}{2}$ ounces. What, then, is the British equivalent of the weight of a kilogram? It is evidently equal to the weight of $3\frac{1}{2}$ ounces $\times$ 10 = weight of 35 ounces = weight of $2\frac{1}{5}$ lbs. (roughly).

The mass of any body is the quantity of matter it contains. —In our country the standard or *unit* of mass is the quantity of matter contained in a lump of platinum of a certain size which is kept at the Exchequer Chambers. This amount of matter is called the *Imperial Standard Pound Avoirdupois*, and we speak of the mass of any other body as being a certain number of times more or less than the standard pound, that is, as containing so many more times as much (or as little) matter than that contained in the imperial standard pound. Unfortunately, this is not a universal standard; in France they have a standard of their own. The French standard is kept at Paris

and is called a *kilogram*, and the system of masses founded upon it is used in all scientific work throughout the world (Fig. 7).



1 lb. 1 Kilogram.

FIG. 7.—Comparative sizes of the British Standard Pound and the Metric Kilogram.

In the metric system a name is given to the mass of water which will exactly fill a *cubic centimetre* at a temperature of 4° C. It is called a *gram*. The same prefixes are used to express fractions and multiples of a gram as have been employed in the case of the metre and litre. The kilogram, or unit of mass, is one thousand times greater than that of a gram, and is the unit in use for ordinary purposes.

METRIC MEASUREMENT OF MASSES.

10 milligrams	= 1 centigram.	10 grams	= 1 dekagram.
10 centigrams	= 1 decigram.	10 dekagrams	= 1 hektogram.
10 decigrams	= 1 gram.	10 hektograms	= 1 kilogram.

Mass is not weight.—If a mass of 1 lb. is dropped from the hand it falls to the ground. If the same mass is hung upon the end of a coil of iron wire, the coil is made longer by the downward pull of the mass fixed to its end. The amount by which a steel spring is lengthened, as the result of such downward pull of masses attached to its end, is used to measure their *weights* in the instrument called a *spring balance.* If a very delicate balance of this kind, like those used in weighing letters, is used, the *weight* of a small piece of iron hung on to the balance can be made to appear greater by holding a strong magnet beneath it. But, though the weight may appear greater, the mass or quantity of matter is, of course, the same whether the magnet is under the iron or not (Fig. 8).

There is thus a very clear distinction between mass and weight, for mass signifies quantity of substance, while weight is a force. In other words, *the mass of a thing is the quantity of matter in it, and its weight is the force with which the earth pulls it.* Unsupported things fall to the ground; a fact which can also be expressed by saying that they are attracted to the earth. Now, even when they are supported, like the objects on a table, the earth attracts them just as much, only the table prevents them from falling, as they would do if there were no table there. The force with which a body is attracted by the earth is its weight. But it must be remembered that this force is just the same whether things actually fall to the ground or not. A spring balance shows the weight of a thing, and masses are compared by means of the ordinary balance or pair of scales.

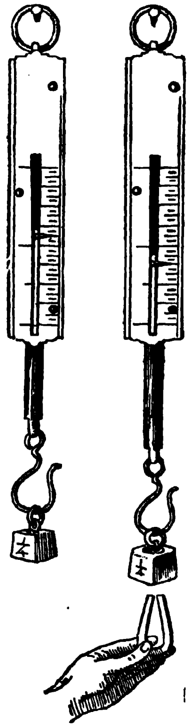


FIG. 8.—The iron weight may be made to appear heavier by a magnet, but the mass does not change.

*6. DENSITY.

i. **The density of different bodies varies.**—(*a*) Determine, by means of a balance, the mass of a cubic centimetre of wood, lead, cork, and marble, and record the results thus:

Mass of the cubic centimetre of

wood (oak)	= ·82	grams.
lead	= 11·35	,,
cork	= ·24	,,
marble	= 2·84	,,

(*b*) Place the cubic centimetre of lead used in the previous experiment in one pan of a balance, and cut a piece of soap from a bar so that it just counterpoises the lead. Find the number of cubic centimetres in the soap.

(*c*) Counterpoise two small bottles of the same size. Fill one with water and the other with methylated spirit. Notice that the bottle of water is heavier than the bottle of spirit, though the volume of each liquid is the same.

(*d*) Counterpoise a pint measure or bottle with some sheet lead. Fill the bottle with water, and place metal weights in the opposite

pan to balance it. Notice that the size of the metal is much less than the size of the pint of water.

The meaning of density.—1. Pieces of different substances of the same size or volume may have unequal masses.

2. Pieces of different substances which have equal masses may have very different sizes or volumes.

It is usual to speak of these facts by saying that things have different *densities*. A pound of feathers, or cotton-wool, has exactly the same mass as a pound of lead, but the feathers (or the cotton-wool) take up much more room, or have a larger volume, than the piece of lead. The matter in the lead must be packed more closely than in the feathers, which accounts for its taking up less room. The shortest way of saying all this is to say that lead is *denser* than either cotton-wool or feathers.

If a small thing is comparatively heavy, then it is called a *dense* thing, or it is said to have a *high density*. If, on the other hand, a large thing has a small mass, it is said to have a *low density*. Moreover, the densities of things having equal volumes are in the same proportion as their masses.

Standard of density.—But to compare densities it is better to have a standard, just as we have a standard of length, the yard, with which to compare other lengths; or a standard of area with which to compare other areas. The density of water at a certain fixed temperature is taken as the standard. Why it is necessary to specify the temperature will be understood later.

The mass of one cubic centimetre of water at a temperature of 4° C. is one gram, and its density is taken as the standard of density, and is called 1. Similarly, a substance, the mass of a cubic centimetre of which is two grams, would be said to have a density of 2, for it must contain twice as much matter as water does, packed into one cubic centimetre. The mass of a cubic centimetre of quicksilver is 13·6 grams, *i.e.* it contains 13·6 times as much matter in one cubic centimetre as there is in one cubic centimetre of water. Its density is therefore 13·6.

Density is the mass of unit volume of a substance.—Suppose a cube of soap and a cube of lead to be cut so as to have equal masses; the soap will evidently be larger than the lead, and it will be just as many times larger as its density is less than the density of the lead. With equal masses, the greater

the density the less is the volume. It follows from this that if the volume of a body is multiplied by its density, we obtain its mass. Or, expressed as an equation,

$$\text{volume} \times \text{density} = \text{mass},$$

from this it follows that

$$\text{density} = \frac{\text{mass}}{\text{volume}}.$$

In using this relation between the volume and mass care must be taken that the values of mass and volume are reduced to the proper units. In all scientific work it is customary to adopt the cubic centimetre and gram as the units of volume and mass respectively.

The ratio of the mass of *any volume* of a substance to the mass of the same volume of water is equal to the *relative density* of the substance, or, as it is frequently called, the *specific gravity*.

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7. SOME METHODS OF DETERMINING RELATIVE DENSITY.

i. **By means of a relative density or specific gravity bottle.**—(*a*) Counterpoise an empty specific gravity bottle, or a flask having a mark on its neck. Fill the flask up to the mark with methylated spirit and weigh it; then empty the flask, dry it, and fill with water up to the same mark. Weigh again, and from the two masses thus determined find the relative density of the spirit, remembering that

$$\text{Relative density} = \frac{\text{mass of substance}}{\text{mass of equal vol. of water}}.$$

(*b*) Following the method of the previous experiment, determine the relative densities of two or three liquids, such as turpentine, milk, vinegar, beer, wine, sea-water or a solution of salt, and ink.

(*c*) Weigh out about 100 grams of shot. Fill the specific gravity flask with water, and counterpoise it together with the shot. Next put the shot into the bottle, and remove the water displaced. Add weights until the index of the balance swings evenly. The weights added must equal the mass of the water displaced, that is, the mass of a volume of water equal in volume to the shot. Therefore

$$\text{Relative density of the shot} = \frac{\text{mass of shot}}{\text{mass of water displaced}}.$$

(*d*) Find by the method used in the preceding experiment the relative densities of such common things as tin tacks (which are really made of iron), bits of slate pencil, brass wire, and brass nails.

ii. **The relative density of liquids determined by balancing columns of water.**—(*a*) Make a U-tube by bending a piece of glass tubing, or by connecting two pieces of tubing of equal bore with a piece of india-rubber. Mount upon a strip of board. Pour quicksilver into

one of the branches of the U-tube until it reaches a horizontal line drawn on the board (Fig. 9).

Now introduce water into one of the tubes, and notice that the mercury on which the water rests is pushed down; afterwards introduce enough water into the other tube to bring the mercury back to its original level. By measuring you find the length of each column is the same. Repeat the experiment with different quantities of water.

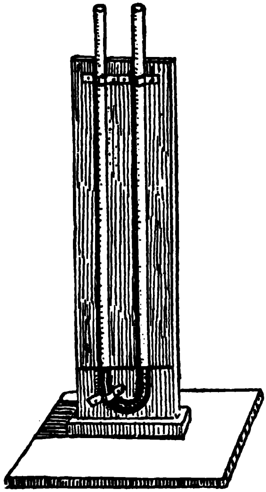

Fig. 9.—An arrangement for balancing columns of liquid. Mercury is in the bend of the tube, up to the line on the upright board.

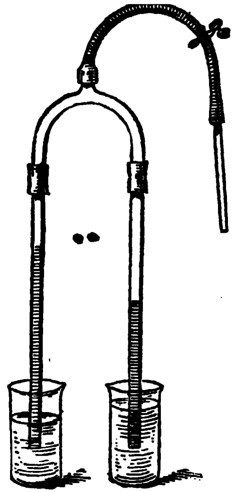

Fig. 10.—Hare's apparatus for comparing the densities of liquids.

(*b*) Remove the water and dry the tubes, and see that the mercury is up to the mark. Nearly fill one of the tubes with some liquid, such as methylated spirit, and balance it with water introduced into the other tube. Measure the lengths of the columns of liquid.

Determine the relative density of the liquid, using the equation that

$$\text{Relative density of spirit} = \frac{\text{length of water column}}{\text{length of spirit column}}.$$

iii. **Hare's apparatus.**—Connect two glass tubes with a three-way tube as shown in Fig. 10. Let the lower ends of the glass dip into different liquids; then apply suction to the short tube at the top, and when the liquids have risen to a convenient height close the clip upon the india-rubber. Measure the height of the liquid in each tube above the level of the liquid below. The heights are inversely proportional to the densities.

Determination of relative densities by relative density bottle.—A simple method of determining the relative densities of substances is to use a specific gravity or relative density bottle. Such a bottle often consists of a small glass flask, holding about fifty grams of water. It is provided with a nicely-fitting ground stopper, with a very small bore through it or a vertical groove cut upon it (Fig 11). It is used in determining the relative density of liquids and powders. To use it, we must first know the mass of the empty bottle and stopper. The bottle is then filled with pure water, the stopper inserted, and the water which is forced through the hole in the stopper wiped off, and the bottle and its contents weighed. In this way the mass of water which just fills the bottle is found. If now we empty the bottle and carefully dry it inside and out, and fill it with the liquid of which the density is required, say spirits of wine, and weigh again, we have the mass of the liquid which just fills the bottle, or the masses of equal volumes of the liquid and water, the proportion of which gives us the relative density of the liquid.

Instead of a bottle of this kind, a flask having a narrow neck around which a horizontal mark has been made may be used The mass of water which fills the flask up to the mark may thus be compared with the mass of liquid which fills it to the same mark.

Fig. 11.—A bottle for use in determining relative densities.

Suppose the mass of water in a relative density bottle was found to be 50 grams, and the mass of the same volume of methylated spirit was found to be 40 grams. Then these numbers show the relative densities of the two liquids, and as we take the density of water as the standard or unit, the density of the spirit is equal to 40 divided by 50. It is thus seen that the relative density of spirit is represented by the fraction $\frac{40}{50}$ or $\frac{4}{5}$, which expressed as a decimal fraction is 0·8.

Determination of relative densities by balancing columns of liquid.—A convenient way to balance liquids against one another, and so compare their densities, is by means of a glass tube bent in the form of a U.

When we arrange a U-tube, as in Fig. 9, the mercury in the bend acts just like a pair of scales, and we are able to balance a column of water in one of the upright arms with a column of the same length in the other. We are then able to argue thus: the columns of water are the same size, or have the same volume, and they balance one another, and consequently their masses must be the same; and, finally, since their masses are equal and their volume the same, they must have the same density.

But suppose we put water in one arm of the U-tube, and enough methylated spirit into the other to make the mercury stand at the same height in the two arms. Here we have a different state of affairs. The column of spirit which balances the column of water will be the longer, hence its size or volume is greater, since the tubes are the same width. But because they balance, their masses must be the same. Which is the denser? Evidently the water is. But how much denser? We can, since the masses are equal, easily calculate this. We may say

$$\text{Relative density of spirit} = \frac{\text{length of water column}}{\text{length of spirit column}}.$$

Hare's apparatus for determination of relative densities.—A convenient arrangement to use instead of a U-tube to determine the relative densities is represented in Fig. 10 and is known as Hare's apparatus. Two straight glass tubes are connected at the top by a three-way junction, upon the unconnected end of which a piece of india-rubber tubing is placed. The lower ends of the tubes dip into beakers containing the liquids the relative densities of which have to be determined. By applying suction to the free end of the rubber tube, the two liquids are drawn up the glass tubes, and the heights of the liquid columns above the level of the liquids in the beakers will be inversely proportional to the relative densities of the liquid employed. The principle is thus precisely the same as that of the U-tube, but by using the form of apparatus here described, the relative densities of liquids which mix can be more conveniently found than by the ordinary U-tube into which the liquids have to be poured.

8. THE PRINCIPLE OF ARCHIMEDES.

i. **Buoyancy.**—(*a*) Suspend a metal cube, or any other fairly heavy object, from a spring balance, and notice the reading of the balance.

This indicates the weight of the object in the air. Immerse the cube in water, as in Fig. 12, and again notice the reading of the balance. It is less than before, and the loss of weight shows the buoyant power or upward pressure of the water.

(*b*) Find the volume of the cube, or other object used in the last experiment, by noticing the volume of the water it displaces in a jar graduated into cubic centimetres.

Hang the object from one end of the beam of a balance, as shown in Fig. 14, and determine its mass in grams. Now stand a vessel of water upon a platform, so that the object is immersed in it, as in the illustration. The balance pan rises. Put gram weights in the pan until the balance sets horizontally as before. You thus find the apparent loss of mass due to the buoyancy or upward pressure of the water. Notice that the number giving this loss in grams is the same as that giving the volume of water in cubic centimetres displaced by the object.

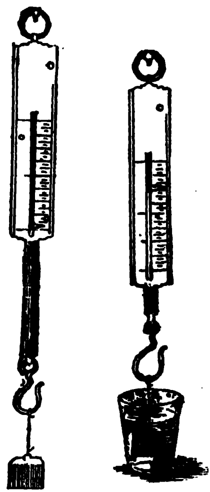

FIG. 12.—The block weighs less when immersed in water than when suspended in air.

(*c*) This principle, viz., that when an object is immersed in water

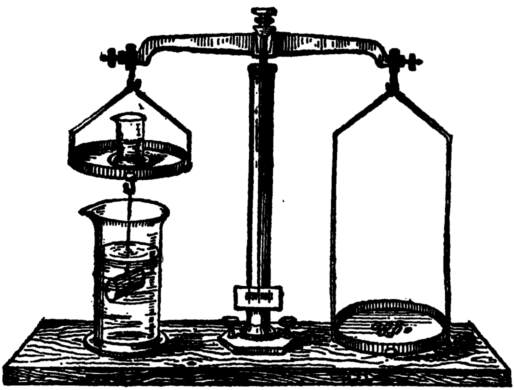

FIG. 13.—When an object is immersed in a liquid it experiences a loss of weight equal to the weight of the liquid displaced by it.

it experiences an apparent loss of mass, or a loss of weight, equal to the weight of water displaced, can be convincingly demonstrated as follows: Suspend an object from the left-hand pan of a balance. Place in the short scale pan a small measuring-glass graduated in cubic centimetres. Counterpoise the suspended object and the measuring-glass together. Now pour water into a graduated jar until the jar is about two-thirds full. Notice the level. Bring the jar under the short scale pan so that the object is immersed as in Fig. 13. Notice the amount of water displaced. Put water gradually into the measuring-glass by means of a pipette. Equilibrium will be restored when the amount of water added is equal to the amount displaced.

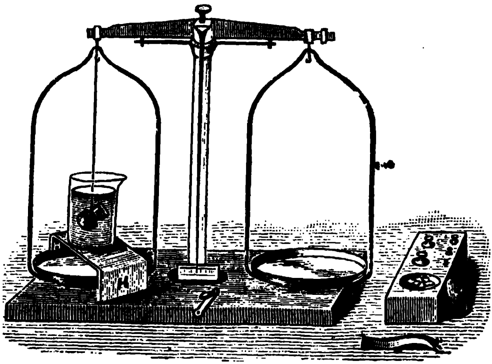

FIG. 14.—How to find the weight of an object suspended in water.

ii. **Determination of density of solids by Principle of Archimedes.**—Suspend the solid the density of which you are going to determine, to one side of the balance, letting it hang in an empty beaker standing upon a platform H, H, as shown in Fig. 14. By weighing, find the mass of the object. Then pour water into the beaker, and weigh the object when immersed in water. By subtracting the number thus found from the mass of the object in air, determine the loss in weight of the solid when suspended in water.

This loss of weight equals the weight of a volume of water equal to the volume of the solid. We can therefore write:

$$\text{Relative density of solid} = \frac{\text{Weight of the solid in air}}{\text{Its loss of weight in water}}.$$

Loss of weight of things immersed in water.—It is easy to prove by experiment that an object weighs less in water than out of it. If a cubic centimetre of lead, or any other heavy material, is hung from a spring balance and then suspended in water, it seems to be the weight of a gram lighter. If two

cubic centimetres are suspended from the balance, the loss is equal to the weight of two grams. In every case the loss of weight measured in this way is equal to the number of cubic centimetres of the solid immersed in the water. A certain volume of water is pushed out of its place by the solid, and for every cubic centimetre thus displaced the object appears to become lighter by the weight of a gram. In every case the loss is equal to the *weight of the water displaced.* This fact brings us to a highly important conclusion, known after its discoverer as the *Principle of Archimedes.*

The Principle of Archimedes—when a body is immersed in water it loses weight equal to the weight of the water displaced by it.—If the body be immersed in any other liquid, then the loss of weight is equal to the weight of an equal volume of that liquid. It does not matter of what substance a thing is made; the amount of loss of weight depends upon the *volume* of the part immersed, and not upon the material.

This principle will enable you to understand why a ship made of iron, and containing all kinds of heavy things, is able to float in water, although the material of which it is made is denser than water. This is because the ship and all its contents only weigh the same as the volume of the water displaced by the immersed part of the hull. Or, the ship as a whole weighs less than a quantity of water the same size as the ship would weigh.

This is why some solids float and some sink when thrown into water. When an object weighs more than an equal volume of water it sinks. When an object weighs less than an equal volume of water it floats. When an object weighs the same as an equal volume of water it remains suspended in the water.

A balloon rises in the air because the gas in the balloon, together with the bag and tackle, weigh less than an equal volume of air. If the balloon were free to ascend it would rise to a height where its weight would be equal to the weight of an equal volume of air.

Determination of relative density of solids.—Knowing that when a body is immersed in water it loses weight equal to the weight of the water displaced by it, you are in possession of all the information necessary for determining the density of a solid compared with water

All you want to know is:

1. The mass of the object; this is determined by weighing it in air.
2. The mass of an equal volume of water; this may be determined in various ways, and can conveniently be found by making use of the Principle of Archimedes.

These determinations can be made with an ordinary balance as follows: The object is suspended by means of a fine thread, from one side of the beam of a balance in such a way that it is completely immersed in water. Then, by weighing, it is found that the mass appears less than when hanging in air. This is because it loses weight in the water. The buoyancy of the water acting upwards overcomes part of the pull of the earth downwards. The difference in the mass of the object in air and its apparent mass when immersed in water gives the mass of a volume of water equal to the volume of the object. From these numbers the density of the solid compared with water as a standard can be at once calculated.

$$\left.\begin{array}{r}\text{Relative density of}\\ \text{the solid}\end{array}\right\} = \frac{\text{Mass of the object in air}}{\text{Mass of an equal volume of water}}.$$

CHIEF POINTS OF CHAPTER II.

TABLE OF MEASURES OF LENGTH, VOLUME, AND MASS.

	Length	Volume	Mass
$\frac{1}{1000}$	Milli-metre	Milli-litre	Milli-gram
$\frac{1}{100}$	Centi-metre	Centi-litre	Centi-gram
$\frac{1}{10}$	Deci-metre	Deci-litre	Deci-gram
1	**Metre**	**Litre**	**Gram**
10	Deka-metre	Deka-litre	Deka-gram
100	Hekto-metre	Hekto-litre	Hekto-gram
1000	Kilo-metre	Kilo-litre	Kilo-gram

VALUE OF COMMON ENGLISH EQUIVALENTS.

1 inch = about $2\frac{1}{2}$ centimetres.	1 gallon = about $4\frac{1}{2}$ litres.
1 foot = ,, 3 decimetres.	1 oz. Troy = ,, $31\frac{1}{10}$ grams.
1 yard = ,, $\frac{9}{10}$ metre.	1 oz. Avoir. = ,, $28\frac{3}{8}$ grams.
1 mile = ,, $1\frac{3}{8}$ kilometre.	1 lb. Avoir. = ,, $\frac{9}{20}$ kilogram.

Mass is the amount of matter in a thing. The British Standard of mass is the Imperial Pound avoirdupois, and the metric standard in common use is the Kilogram. The metric standard of mass used in scientific work is the *gram*. Masses may be compared by a pair of scales.

The **weight** of an object is the force with which the earth pulls it to itself. Weight can be measured by a spring balance.

Density.—Equal volumes of different substances may have different masses. Equal masses of different substances may have different volumes. Or, different substances may have different densities.

Specific gravity, or relative density, is the ratio of the mass of any volume of a substance to the mass of an equal volume of water.

$$\text{Relative Density} = \frac{\text{mass (or weight) of a substance}}{\text{mass (or weight) of an equal volume of water}}.$$

Balancing columns of liquids.—The densities of two liquids balanced in a U-tube are in the inverse proportion of the lengths of the columns. Or,

$$\text{Relative Density of a liquid} = \frac{\text{length of water column}}{\text{length of liquid column}}.$$

Principle of Archimedes.—When a body is immersed in a liquid it loses weight equal to the weight of the liquid displaced by it.

Expressed differently, the up-thrust experienced by an object in water is equal to the weight of the water displaced.

The number of cubic centimetres in an object is also the number of cubic centimetres of water displaced by such an object when it is totally immersed in water.

EXERCISES ON CHAPTER II.

1. Multiply 10·4 square centimetres by 15·5 decimetres, and state the result both in cubic centimetres and in litres.

If the volume in question were filled with water at 4° C., what would the weight of the water be? (1897.)

2. What is the cubical content, in litres, of a box of which the inside dimensions are as follows: length 25 centimetres, breadth 12 centimetres, and depth 8 centimetres? What is the weight in kilograms of the water it would hold? (1898.)

3. One pint is equal to 34·7 cubic inches, and 1 inch is equal to 2·54 centimetres. How many pints are there in 1000 cubic centimetres?

What is the name given to a volume of 1000 cubic centimetres? (1898.)

4. How would you determine the volume of a pebble in cubic centimetres? (P.T. 1897.)

5. Explain how the metric units of volume and length are related. Is there any such simple relation in the case of British units?

6. What is meant by a unit of length, and why is it necessary to have such a unit?

Give particulars of the units of length in use in this country and on the Continent, and give your opinion as to whether one of the units you give is more convenient than the others, and if so, why? (1899, Day.)

7. What particulars concerning a lump of lead could you determine (*a*) by using a spring balance, (*b*) by means of a pair of scales?

8. Distinguish between the mass and weight of an object.

9. Define mass, volume, and density, and state the relation that exists between them.

Suppose you were given two irregular pieces of metal, one of which was gold and the other gilded brass. How would you find out, by a physical method, which piece was gold? (P.T. 1897.)

10. Explain why a ship made of iron will float in water, though iron itself is heavier, bulk for bulk, than water? (P.T. 1897.)

11. A number of nails are driven into a rough piece of wood, one cubic centimetre of which weighs 0·5 gram. It is required to find the weight of the nails without pulling them out. How could this be done by experiment? (P.T. 1897.)

12. A covered tin canister having a volume of 88 cubic centimetres contains just enough shot to sink it to the top of the cover when placed in cold water. Determine from this information:

(*a*) The weight of the canister and shot;

(*b*) The weight of the water displaced by the canister. (P.T. 1897.)

13. Describe an experiment to show that when a solid body is immersed in water its apparent loss of weight is equal to the weight of the water it displaces. (1898.)

14. Describe the method of determining the specific gravity of a body by weighing it alternately in air and water.

If a body weighs 14·4 grams in air and 12 grams in water, what is its specific gravity? (1897.)

15. Describe how you would measure the density of a piece of stone, giving a sketch of the apparatus you would employ. (1898.)

16. Describe a method of determining the specific gravity of a liquid. (1897.)

17. Explain what is meant by specific gravity. A body of specific gravity 5 weighs 20 grams in air; what will the body weigh when immersed in water? (1897.)

18. A bottle weighs 2 ounces. When holding $3\frac{1}{2}$ ounces of shot it will just float in water, when holding 3 ounces it will just float in oil, and when holding $3\frac{3}{4}$ it will just float in brine. Find the specific gravity of the oil and the brine. (P.T. 1898.)

19. A piece of metal weighs $19\frac{1}{2}$ grams in air, and $17\frac{1}{4}$ grams in water. What is its specific gravity?

With what apparatus and in what manner would you find the weight in water? (P.T. 1898.)

20. A stone, weighing in air 1 kilogram, is suspended by a piece of cotton so that it is entirely immersed in water. On attempting to lift the stone out of the water the cotton breaks when the stone is partly out of water. Why is this?

If, when the stone is completely immersed, the cotton would bear an additional pull equal to the weight of 150 grams, what volume

of the stone will be out of the water when the cotton breaks? (1899, Day.)

21. An ink-bottle consists of a cube of glass, out of which has been cut an exactly hemispherical hole. What measurements and what calculations would be necessary to determine the volume of the glass?

How could the previous result be verified or checked, if you had a beaker of water, a gummed paper strip, and a burette or a measuring cylinder? (L.C.C. Int. Sch., 1900.)

22. A beaker of water stands on the pan of a table spring balance. A block of iron hangs from the hook of an ordinary spring balance, and is gradually lowered into the water till completely submerged. Will there be any changes in the readings of the balances? If so, what changes, and why? (L.C.C. Int. Sch., 1900.)

23. You are given a small rectangular block of brass, and you have at your disposal a measuring rod divided into centimetres and millimetres, a balance and weights, some fine wire, and a vessel of water. How will you determine, by two perfectly independent methods, so that the results may form a check on one another, the volume of the block? Describe exactly what calculations you will have to make, and say upon what scientific principle, if any, each of your methods depends. (L.C.C. Int. Sch., 1898.)

24. Two blocks of glass, each having a volume of 10 c.c., are hung from the scale-pans of a balance by means of hooks under the pans, and balance one another. Under one is brought a beaker of water, under the other a beaker of alcohol, so that the blocks are immersed in the liquids. The balance is now disturbed, and it is found that 1·82 grams have to be added to one pan to restore equilibrium. To which pan has this weight to be added, what is the explanation of the fact, and how can you determine from the figures now at your disposal the density of the alcohol? (L.C.C. Int. Sch., 1898.)

25. Explain the statement that "the specific gravity of iron is 7·8." Describe one method of finding this specific gravity. (Queen's Sch., 1899.)

CHAPTER III.

MEASUREMENT OF TIME, ANGLES, AND MOTION.

9. TIME.

i. **Principle of the pendulum.**—Attach a weight to the end of a cord. Fix the cord in such a way that the pendulum can oscillate freely. Set it oscillating, and notice how long it takes for the pendulum to complete a given number, say twelve, swings. Keeping the cord exactly the same length, attach a heavier weight and repeat the experiment. The time of swing remains unaltered. Keeping any one weight, observe the time taken to complete twelve swings when the length of the cord is varied. It will be seen that the time of swing varies with the length of the cord. Notice also that whether the pendulum makes a wide oscillation or a very small one, the time taken is the same.

ii. **A pendulum beating seconds.**—Vary the length of the string until the pendulum makes thirty swings in half a minute, that is, it beats seconds. Measure the distance from the point of suspension to the centre of the weight; it will be found to be about 39·2 inches.

Motion.—The word motion merely means change of place, but it involves ideas of distance, time, and direction. The distance through which a body moves, or is moved, can be expressed in any convenient units of length, such as those already described. Methods of measuring time and determining directions by angles must, however, be explained before the exact significance of motion can be understood.

Unit of time.—The unit of time is the second, and is the same in both the British and metric system of units. This interval of time, as everyone knows, is the 86,400th part of a day, the 3,600th part of an hour, and the 60th part of a minute.

A solar day is the interval between two successive solar noons at one place. This interval, however, varies in the course of the year, so an average is taken of all of them, and

the length of time thus derived is called a *mean solar day*. The second is defined as the 86,400th part of this duration of time. Observations show that a pendulum, 39·139 inches long from the point of suspension to the centre of the bob, if set swinging in the latitude of Greenwich, completes one swing in a second of time. It is necessary to specify the place because, on account of the fact that the earth is not a perfect sphere, and is in rotation, the rate at which a pendulum swings differs slightly in different latitudes.

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10. ANGLES.

i. **Measurement of angles.**—(*a*) Draw two lines at right angles to one another, as N.S., E.W. (Fig. 15). Push a pin firmly into the point *O* where the lines intersect. Fix a loop at each end of a short piece of strong thread. Put one loop over the pin and a pencil in the

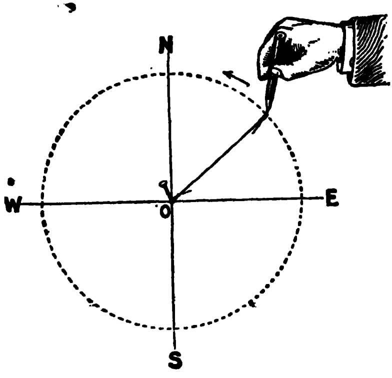

FIG. 15.—Principle of angular measurement.

other, and, keeping the thread tight, draw a circle with the pencil in the loop. Draw a second circle larger or smaller in size. Notice that (1) each circle contains four right angles, (2) that the angle between the direction of the thread at any instant and the direction at starting is independent of the length of the thread.

(*b*) Draw a large circle upon a sheet of cardboard, and divide the circumference into 360 equal parts; each of these parts is called a *degree*. Cut two narrow strips of card, of a length slightly greater than the radius of the circle, and fix one end of each to the centre of the circle (Fig. 16). Arrange the strips together over one of the divisions of the circumference. Keep one fixed, and move the other in the opposite direction to the movement of the hands of a timekeeper.

The difference of direction at any instant, or the angle between the two strips, is indicated by the divisions of the circumference of the circle.

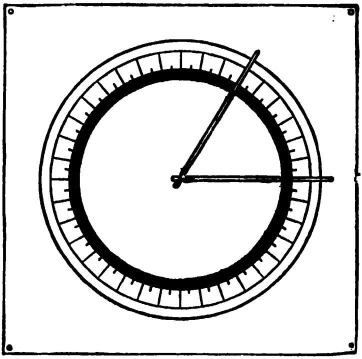

FIG. 16.—Divided circle, and 'hands' to illustrate angular measurement.

ii. **Construction of any angle.**—To draw two lines inclined at any given angle, Fig. 17 may be used. Place the paper, upon which the lines are to be drawn, under the page with this figure upon it. Make a pin-prick at the centre of the circles, another at the 0° division of the circumference, and a third at the point on the circumference corresponding to the number of degrees in the angle required. Then take away the drawing-paper and draw lines from the central pin-prick to the two others. These lines include the angle required.

iii. **Determination of the magnitude of an angle.**—(*a*) Draw any angle upon a piece of paper. Let the lines including the angle be several inches long. Push the point of a pin through the centre of Fig. 17,

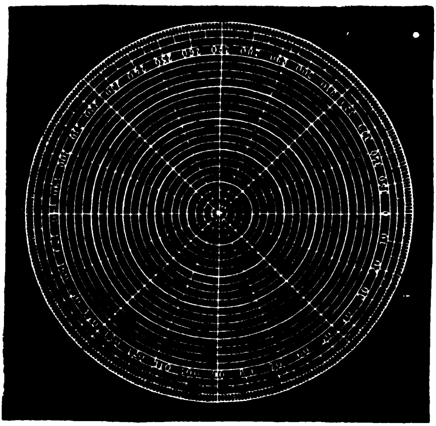

FIG. 17.—Circular protractor for the measurement of angles.

and place the paper, having the angle drawn upon it, under the figure as before, so that the point of the pin pricks into it where the

two lines meet. Keeping the paper fixed, draw two lines upon the page corresponding to the two lines which include the angle to be measured. The magnitude of the angle can then be seen by noticing the number of degrees between the two points where these lines cut the circumference of Fig. 17.

(*b*) Obtain an ordinary protractor. Draw any angle upon a piece of paper, and place the protractor so that the bottom edge is upon one of the lines, and the * at the middle point of this edge upon the vertex of the angle (Fig. 18). The magnitude of the angle will be found by noticing where the second line forming the angle crosses the protractor.

Unit of angular measurement.—The general plan adopted in measuring angles is to divide a circle into 360 equal parts, and to call each part a *degree* (1°). Thus, a movable hand pivoted at the centre of a circle has traced out an angle of one degree when it has gone round $\frac{1}{360}$th part of a complete revolution. When it has performed one quarter of its journey round, it has made an angle of ninety degrees, or a *right angle*, as it is called.

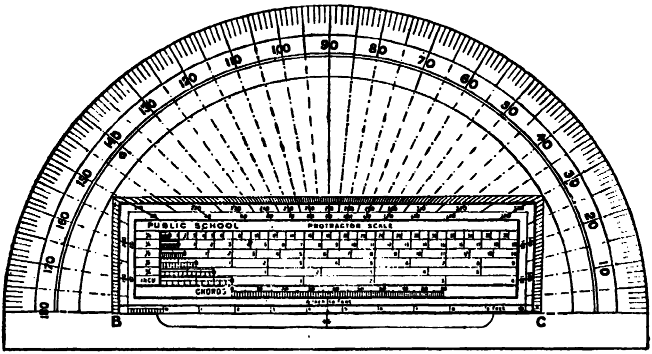

FIG. 18.—Semicircular and rectangular forms of protractor, used for the measurement of angles.

The minute hand of a watch or clock moves through 360 degrees in an hour, or ninety degrees in every quarter of an hour, and this is true whatever the size of the timepiece. This reveals a very important fact, viz., that the size of an angle is quite independent of the length of the lines between which it is contained or the *arms* of the angle. All circles contain 360 degrees (Fig. 17.) All right angles contain ninety degrees, so there are four right angles to every circle. In accurate

measurement, parts of a degree are measured, and the subdivisions used are that one degree equals sixty minutes, and one minute (1′) equal sixty seconds (60″).

The magnitude of an angle can be found by means of a protractor, two forms of which are shown in Fig. 18. The simplest is the semi-circle divided into degrees, but a more common form is oblong in shape. The marks upon the edge of a protractor of this kind are obtained from the corresponding divisions on a semi-circle in the manner represented in the illustration.

11. MOTION AND VELOCITY.

i. **Motion.**—Place a number of marbles in a tray. Disturb them by shaking the tray, or in any other way; they all acquire motion, but move in various directions and at different rates.

ii. **Speed.**—Shoot a marble along a table, or let it run round the rim of a tray. The marble travels with a certain speed or rate of motion, and it may be given this speed in any direction.

iii. **Velocity.**—Bowl a marble along a table in a definite direction, and observe as nearly as possible the number of seconds taken to perform the journey. The distance thus traversed, divided by the number of seconds occupied in traversing it, gives the rate of motion in feet per second. The velocity of a body is its rate of motion in a definite direction.

iv. **Uniform velocity.**—Make several lines crosswise on a long table at a distance of one foot apart. Push a cylinder or marble along the table at such a rate that the length from one line to the next is traversed in one second. The velocity of the object is thus one foot per second and is uniform during the movement.

v. **Variable velocity.**—Shoot a marble or roll a cylinder along the table with the marks upon it, and notice the number of seconds taken in passing from the first to the last mark. In this case the same total distance is traversed as before, but the velocity is variable, that is, the body does not move through equal spaces in equal times throughout its movement as it is gradually coming to rest. If a length of 8 feet is traversed in 4 seconds, what is the average velocity?

vi. **Graphic representation of velocity.**—(*a*) Taking a line an inch long to represent a velocity of one foot per second, draw lines representing velocities of $3\frac{1}{2}$, $2\frac{3}{4}$, 4, and $1\frac{1}{4}$ feet per second, making the lengths of the lines proportional to the rates of motion.

(*b*) Draw a line to represent the velocity of a river flowing at the rate of 2 miles an hour. Suppose a man who can row 6 miles an hour in still water to be rowing in this river. Draw lines to represent his velocity with reference to the bank when rowing (1) with the stream, (2) against the stream.

(*c*) Draw a large circle upon a sheet of paper. Draw two diameters at right angles to each other, as in Fig. 15. Taking $\frac{1}{2}$ inch to represent a velocity of 1 foot per second, and starting from the centre of the circle, represent by graphic construction the path of a body moving with the following velocities:—2 feet per sec. N.E.; 2 feet per sec. N.; 3 feet per sec. W.; 4 feet per sec. S.E.

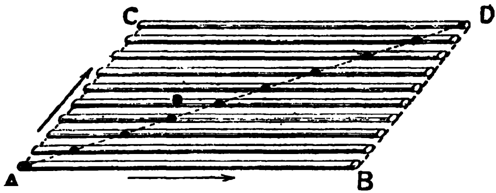

FIG. 19.—To illustrate the combination of two velocities, and the principle of the parallelogram of velocities.

vii. **Combination of two velocities.**—Place a wide glass tube along a table near one edge. Let a marble roll through the tube, and as it does so roll the tube across the table. Suppose a second is taken for the tube to move from its first to its last position, then the positions of the marble at intervals of a tenth of a second are shown in Fig. 19. The marble enters at A and emerges at D; the distance it has travelled in the direction of the length of the table is therefore represented by AB. The distance it has travelled *across* the table is in the same way represented by AC. Construct a parallelogram $CABD$ with lines proportional to CA and AB as sides. The diagonal AD represents the path actually traversed by the marble.

Definition of motion.—The word *motion* is meant to convey the idea of *change of place*. The simplest forms of motion are changes in the positions of bodies with regard to one another. When a boy runs down the street he is in *motion*; as regards the houses and lamp-posts he moves. To fully describe the boy's motion it would be necessary to know his *velocity*, that is, the *direction* in which he is moving or the *line* along which he runs, and the *rate* with which he travels. If during every second through which he moves he travels over a line of five yards in length, he has a *uniform* velocity of five yards a second.

But suppose he does not move regularly over five yards in every second; he sometimes dawdles, sometimes stops to look at a shop, at other times he puts on a spurt to make up for lost time. How should we describe his motion now? His rate varies from time to time, or his velocity is *variable*, and to describe such a variable velocity it is usual to speak of the

velocity *at any instant* as being a certain number of yards per second. Suppose the boy moving with a variable velocity had at a given instant a velocity of eight yards per second. If he continued to move at the same rate he would travel over eight yards in the succeeding second.

Average velocity.—But it is sometimes better to find the *average velocity* of the moving body. Returning to the boy, suppose he travelled 800 yards in 400 seconds; if we divide the first number by the second we obtain the boy's average rate, namely, two yards in a second; this, then, is the rate with which he would have had to travel, if he moved uniformly, in order to complete his journey in the same time.

The *unit of velocity* is generally taken as being a velocity of one foot per second. Thus a velocity of six means a velocity of six feet per second.

Measurement of uniform linear velocity.—It is a very simple matter to calculate the velocity of a body moving uniformly in a straight line when the distance it has travelled, measured in units of length, and the time it has taken to perform the journey, measured in units of time, are known. All that has to be done in order to find its uniform velocity is to divide the number of units of length passed over by the number of units of time taken to complete the distance. Thus:

$$\text{Uniform velocity} = \frac{\text{space traversed}}{\text{time taken}}.$$

Velocities can be completely represented by straight lines.—To completely determine a velocity all we want to know are its magnitude (or the distance travelled in a given time) and its direction. But, as is well known, a straight line can be drawn in any direction and of any length; and we can arrange that its length shall contain as many inches or feet, whichever is more convenient, as there are feet or yards per second of velocity, depending on the way in which we decide to measure our velocities. We can therefore completely represent velocities by straight lines.

Composition of velocities.—Think of the case of a marble moving along a tube with a uniform velocity, when the tube itself is all the time being uniformly moved across a table. It is evident that since the marble is in the tube it must have the same velocity *across* the table that the tube has; and at the same time it moves along the tube, that is, in a direction at right angles to

its former velocity. It has two independent velocities. Similarly, we can think of a ship sailing across the ocean with a man on deck walking from one side of the ship to the other. The man has two velocities. He is moving onwards with the ship at a certain velocity, and at the same time he is moving across the ship with another velocity.

But yet a body can only move at any instant in one direction with one definite velocity. How, then, shall we find the actual velocity at any instant in the case of the marble or of the man? The velocity which we want to find is called the *resultant* of the two independent velocities, which are themselves spoken of as *components*. If the two velocities have the same direction, all we have to do is to add them to obtain the resultant, or if they are in opposite directions along the same straight line we subtract them. If they have directions which make an angle with one another, it is clear that the resultant must be somewhere between the components. Referring to the case of the marble, let OA (Fig. 20) represent by its length the number of inches the marble moves along the tube in a second, and OB the distance moved by the tube, and consequently by the marble in the same time across the table. The arrows give the direction of the movement. Draw BR parallel to OA and AR parallel to OB, thus completing the parallelogram, then the line OR represents the resultant velocity, both in magnitude and direction. In just the same way OA could stand for the ship's velocity and OB for the man's, then OR would represent the direction and magnitude of the man's actual velocity. This principle is called the *Parallelogram of Velocities.*

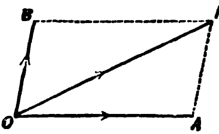

FIG. 20.—Parallelogram of velocities.

12. ACCELERATION.

i. An instance of accelerated velocity.—Obtain a smooth board about six feet long, having a slight groove cut in it from one end to the other (Fig. 21). Incline the board slightly at one end. Place a marble or other small sphere near the raised end and let it roll down

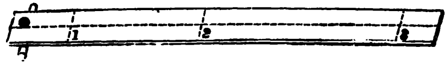

FIG. 21.—A grooved board for experiments to illustrate acceleration.

the board. Notice that as it moves its velocity increases. To show that the space traversed increases every second, fit up a seconds' pendulum and set it in motion. Let the bob of the pendulum strike against a sheet of paper or some other light object at the end of each swing, so that you can hear when the seconds commence. Now start the marble from a mark upon the board exactly when the pendulum taps the paper on one side. Notice how far the marble has rolled by the time the pendulum taps the paper on the other side. Make a mark at the place reached, and do the same for succeeding seconds until the marble rolls off the board. Measure the length of board traversed by the marble in each second. The distances will be found to increase in proceeding down the board from the starting place.

Meaning of acceleration.—An express train starting from a terminus begins to move slowly, and, as the journey proceeds, the rate of motion goes on increasing until the train gets its full speed. A stone let fall from a height similarly starts from rest, and as it moves it travels faster and faster until brought to a standstill again on reaching the ground. Or, we might imagine a cyclist starting for a run, and regularly increasing his speed until he could not go any faster. In all these examples the velocity of the moving body has regularly increased, and the rate at which the change has taken place is spoken of as *acceleration*.

Acceleration is the rate of change of velocity.—But acceleration may be of an opposite kind to the instances given above. Reverse each of the examples and consider what happens. An express train going at full speed approaches a station and its velocity is regularly diminished until it is brought to rest at the platform. A stone is thrown upwards with a certain velocity, it moves more slowly and more slowly until it comes to rest, and then starts falling. A cyclist travelling at full speed slackens his rate regularly until he comes to a standstill. In all these cases we have examples of an acceleration of an exactly opposite kind to the previous instances, but yet an acceleration. In ordinary language this kind of acceleration is given a name of its own, viz. *retardation*.

Measurement of uniform acceleration.—In measuring a regular or *uniform acceleration*, we must know what addition to, or subtraction from, the velocity of the moving body there has been during each second of its journey. Suppose there is an addition of one foot per second to the velocity of a moving body, and that it has taken one second to bring about this change, we should refer to this as an acceleration of one foot per second in

a second, or *one foot per second per second.* An acceleration which increases the velocity is referred to as *positive*, while that which diminishes it is *negative.* The first examples given above are instances of positive acceleration, while when we reverse them they afford cases of negative acceleration.

Unit of acceleration.—As in every other measurement so, when we wish to measure accelerations, we must have a unit in terms of which we can express the quantity under consideration. *The unit of acceleration is an increase of unit velocity in a unit of time*; it is generally taken as equal to *an increase of velocity of one foot per second per second.* An acceleration of *two units* would thus be an increase of velocity of *two* feet per second per second; similarly, an acceleration of three units equals an increase of velocity of three feet per second per second, and so on for any number of units.

Acceleration, like velocities, can be represented graphically by straight lines.

CHIEF POINTS OF CHAPTER III.

Unit of time.—In physical measurements the unit of time adopted is the mean solar second, that is, the 86,400th part of a mean solar day. The unit is founded on the average time required by the earth to make one complete rotation on its axis relatively to the sun considered as a fixed point of reference.

A pendulum about 39·2 inches in length beats seconds.

Measurement of angles.—One degree (1°) is $\frac{1}{90}$ of a right angle and $\frac{1}{360}$ of a circle.

60 seconds of arc (60″) = 1 minute of arc (1′).
60 minutes of arc (60′) = 1 degree (1°).
90 degrees = 1 right angle.
4 right angles = a complete revolution.

Motion is change of place. *Speed* is rate of motion in any direction.

Velocity is the rate of motion in a given direction. When a body's velocity is *uniform* it moves over equal distances in every second, when it is *variable* unequal distances are moved over in equal times.

$$\text{Uniform velocity} = \frac{\text{No. of units of length travelled}}{\text{No. of units of time taken}}.$$

The unit of velocity is generally taken as being a velocity of one foot per second. Velocities can be completely represented by straight lines. The resultant of two velocities can be determined by the *parallelogram of velocities.*

Acceleration is the rate of change of velocity. In measuring uniform accelerations we must know what addition to, or subtraction

from, the velocity of the moving body there has been during each second of its journey.

The unit of acceleration is an increase of unit velocity in a unit of time. It is generally taken as equal to an increase of velocity of one foot per second for each second.

EXERCISES ON CHAPTER III.

1. A line is drawn upon the floor of a railway carriage from door to door. When the carriage is at rest a ball is dropped from the roof and falls upon this line. What difference would be observed:

(*a*) If the train is moving when the ball is dropped?

(*b*) If the train starts when the ball is half way down?

(*c*) If the ball is dropped when the train is in motion, but the train stops suddenly when it is half way down? (P.T. 1897.)

2. A man walks backwards and forwards on the deck of a steamer along a line parallel to the direction in which the steamer is moving. If the man walks at the rate of 3·5 miles an hour, and the steamer goes through the water at the rate of 8·4 miles an hour, what is the velocity of the man with reference to the water (1) when he is walking towards the bow of the boat, and (2) when he is walking towards the stern? (1898.)

3. How is the unit of time, the second, defined? Describe how you would fit up an apparatus to beat seconds. (1899.)

4. Define an angle. What is a right angle? Describe how you would construct an angle of 30° and one of 45°.

5. Give examples of uniform linear velocity, variable linear velocity, uniform angular velocity, and variable angular velocity.

6. Explain clearly an experiment to illustrate how the resultant of two linear velocities may be determined. Draw a diagram showing the construction known as the parallelogram of velocities.

7. What is meant by acceleration? Give examples of uniformly accelerated velocities (*a*) where the acceleration is positive, (*b*) where the acceleration is negative.

8. How are (*a*) uniform linear velocities, (*b*) uniform positive accelerations, measured?

9. Draw triangles of which two of the angles are respectively 90° and 30°, and one of the sides 8 cm. long. Determine by measurement what may be the lengths of the other sides. (Junior Oxford Local, 1900.)

10. What is acceleration? What is the unit of acceleration usually adopted, and what does the term mean? (Junior Oxford Local, 1900.)

CHAPTER IV.

INERTIA. GRAVITATION. PARALLELOGRAM OF FORCES.

13. INERTIA.

i. **To show that a mass at rest tends to remain so.**—Suspend a heavy mass, not less than 28 lbs., from a cord. Tie a piece of cotton or thread to the mass, and then attempt to move it by pulling the thread sharply to one side. The thread will break and the mass will hardly be moved. The mass can, however, easily be pulled to one side if the pulling force is gradually applied.

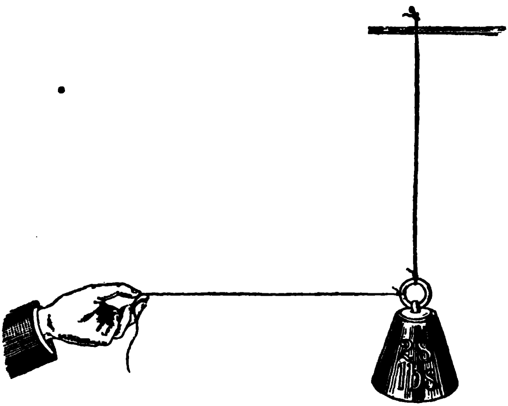

Fig. 22.—Experiment to illustrate the tendency of a body to preserve its state of rest or motion.

ii. **A moving mass requires force to stop it.**—Swing the heavy mass used in the preceding exercise to and fro by means of a thread attached to it. While it is swinging away from your hand, stop your hand suddenly. The thread will break and the mass will proceed on its swing.

Inertia.—Common experience tells everyone that things do not move of themselves. An object at rest remains at rest until it is forced to move. Moreover, if it is moving it tends to go on moving in the same direction and with the same velocity until made to change by the application of force. In a word, dead matter is helpless and conservative. It does nothing by itself, and objects to alter its condition whatever that condition may be. *The inability shown by a material body to change by itself its condition of rest or of uniform motion in a straight line is called its inertia.* It is exemplified when a cyclist is suddenly stopped, for the tendency to continue moving is so great that the cyclist, if he is travelling quickly, is shot over the handle-bar of his machine. This law of inertia is often spoken of as Newton's First Law of Motion.

First law of motion.—*Every object remains at rest or moves with uniform velocity in a straight line until compelled by force to act otherwise.*

This law, which Newton first stated as being always obeyed by bodies in nature, means, first, that if a body is at rest, it will remain still until there is some reason for its moving—until some outside influence, which is called a *force*, acts upon it. In fact, the law really supplies us with a definition of force. Nobody finds any difficulty in understanding the rule so far. But it is not so easy to see the meaning of the words referring to uniform motion in a straight line. An example will make this clear. Consider a ball moving uniformly along ice. After a time the ball comes to rest, and therefore it does not continue in a state of uniform motion. But it moves for a longer time on ice than it would do on a road. The ice is smoother than the road, and there is a connection between the roughness or smoothness and the length of time during which the ball moves. If the ice could be made smoother and smoother, the ball would move for a longer and longer time, and if both the ball and the ice were perfectly smooth, there is no reason why the ball should ever stop. The roughness or friction represents, then, the force which causes the ball to change its state of uniform motion for one of rest. If a body in a state of uniform motion could be placed outside the influence of what Newton has called "impressed forces" it would afford us an example of *perpetual motion.* But because these impressed forces cannot be eliminated perpetual motion is impossible.

Definition of force.—Newton's first law enables force to be defined. *Force is that which produces, or tends to produce, motion in matter; or alters, or tends to alter, the existing motion of matter.* It must, however, be clearly understood that by defining force we do not get to know anything more about it. Nobody can tell what force is. All we can know are the effects produced by force.

The force of gravitation.—Experiments and observations made by Newton led him to the conclusion that it was the rule of nature for every material object to attract every other object, and that this force of attraction is proportional to the masses of the bodies; a large mass exerts a greater force of attraction than a small mass. But the farther these bodies are apart the less is the attraction between them, though it is not less in the proportion of this distance, but in that of the square of the distance. This diminution of a force according to the inverse proportion of the square of the distance applies to so many cases that it ought to be clearly understood before proceeding. Suppose two bodies of equal mass are one foot away from one another and attract each other with a certain force. If the distance between the masses is doubled, the strength of the attraction between them is only one-quarter of what it was; for the square of 2 is $2 \times 2 = 4$ and the inverse of 4 is $\frac{1}{4}$. In the same way, if the bodies are placed three feet apart, the force of attraction is $\frac{1}{9}$ of the original force. Putting Newton's law together it stands thus: *Every body in nature attracts every other body with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between the bodies; and the direction of the force is in the line joining the centres of the bodies.*

Consider the case of a cricket ball on the top of a house. The earth attracts the ball, and, by Newton's law, the ball attracts the earth. The ball, if free to move, falls to the earth; to be correct, however, we must think of the ball and the earth moving to meet one another along the line joining their centres. But the ball moves as much farther than the earth as the earth's mass is greater than that of the ball; and for practical purposes this is the same as saying that only the ball moves and that the earth remains still.

This force of attraction between all material bodies is called the force of gravitation, but we must again point out that this is only a name. Calling this force "gravitation," and the rule

according to which it acts the "law of gravitation," does not teach anything about the nature of the force itself.

The attraction of gravity.—Bearing in mind that weight is really a measure of the attraction between an object and the earth, it will be clear from Newton's law of gravitation that since a thing up in a balloon is farther away from the earth (which acts exactly as if its whole mass were collected at its centre) than when at the sea-level, the weight of this thing ought to be less than it is at the sea-level. This is found to be the case, but, to actually demonstrate the difference in weight, the weight must be measured by a spring balance as in Experiment 5, i. (*c*).

Similarly, because the earth is not a perfect sphere, but is flattened at the poles, points at the surface of the earth in the region of the tropics are at a greater distance from the centre than points similarly situated in the neighbourhood of the poles. Consequently, the weight of a mass situated on the earth in the tropics should be less than the weight it would have if it were moved into the polar regions. This has been found to be the case.

The rotation of the earth is another disturbing influence. While places on the equator are carried round with a velocity of over a thousand miles an hour, those near the poles have but a very small velocity of rotation, while the pole itself is at rest. It is clear that if we consider a mass at the equator its tendency is to obey the first law of motion (p. 42), and to fly off at a tangent, and part of the force of gravitation is expended in preventing this flight—the remainder of the force of gravity is operative as the weight of the mass under consideration. At the pole there is no tendency to move off tangentially, and the whole of the force of gravitation is felt as the weight of the body. For this reason alone the mass would weigh less at the equator. At places intermediate between the poles and the equator the diminution in the weight of the body, or the diminution in the acceleration due to gravity, is less; it diminishes as the nearness to the pole is increased.

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14. PARALLELOGRAM OF FORCES.

i. Relation between tension and extension.—Clamp a thin india-rubber cord with a wire by its side as in Fig. 23, and a tray

suspended from the lower end. Place 10 grams in the tray and measure the elongation produced by it—that is, measure the distance between the pin and the bottom of the wire. Place another 10 grams in the tray and again notice the extension produced. By subtracting this reading from the former one, you can find the extra extension produced by the additional 10 grams. In the same way, find the extension produced by 30 grams, 40 grams, and so on, up to 100 grams, also determining in each case the extension for the additional 10 grams. Record thus:

Load.	Total Extension.	Extension for 10 grams.

ii. **Representation of forces by lines.**—Draw vertical lines to represent the extensions produced by the various loads, and also lines to represent the extension for every additional 10 grams. As the loads represent forces, the lines will represent the extension produced by various forces. You will find that the extensions are proportional to the forces—that is, double the force double the extension, and so on. *The strength or magnitude of a force can thus be shown by the length of a line.*

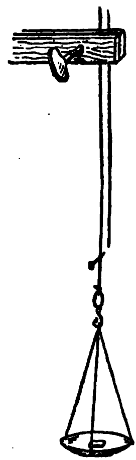

FIG. 23.—**Experiment to show the extensions produced by different forces.**

iii. **Parallelogram of forces.**—The following experiments illustrate how the *directions* as well as the *magnitudes* of forces can be represented by lines.

(*a*) To the middle of a piece of elastic cord about six inches long fasten a piece of the same cord about three inches in length. From the point where the three cords meet measure off an equal distance, say two inches, and put a pin through each cord at this distance.

Fasten the pin at each end of the six-inch piece of cord upon a sheet of paper lying flat upon a drawing board or table. The cord should lie in a straight line between the pins, but it must not be stretched (Fig. 24). Now pull the third cord in any direction so as to stretch the others as well as itself, and fasten its pin in the board while the cords are thus stretched (Fig. 24). Make a pin mark upon the paper at the point where the cords meet, and then pull the pins out of the paper and put them and the cords aside. Pin-holes will be marked at *ABCD* in Fig. 24. Mark off two inches from each of the lines, starting from *A*, *B*, and *D* respec-

tively. The lengths *EC*, *FC*, and *GC* thus represent the amounts by which the cords have stretched.

(*b*) Construct the parallelogram *ECFH* by drawing *EH* and *FH* parallel to *CF* and *EC* respectively. Draw the diagonal *CH*; it will be found to have the same length and be in the same line as *CG*.

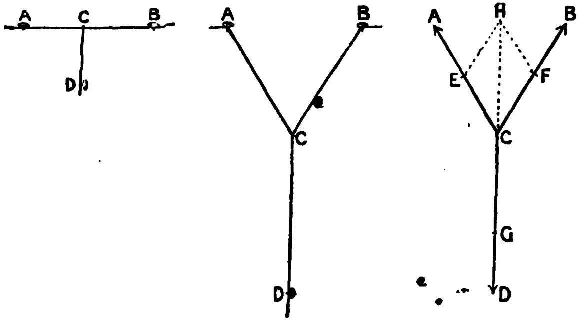

FIG. 24.—A three-way elastic cord, used to illustrate the principle of the parallelogram of forces.

Assuming that the extensions are proportional to the forces (and they practically are so in this case), the two sides *EC*, *CF* of the parallelogram represent two of the forces both in magnitude and direction, and the third force, which is equivalent to the other two taken together, is represented on the same scale by the diagonal of the parallelogram.

(*c*) Repeat the experiment with the cords stretched by different amounts and in different directions. Construct a parallelogram similar to *ECFH* for each case.

When the cords are arranged in any position they represent three forces acting upon the particle *C*. Since *C* is at rest, the force represented by *CG* produces the same effect as the two forces represented by *CE*, *CF*, taken together. If, therefore, a force equal in magnitude to *CG*, and acting in the direction *CH*, is substituted for *CE*, *CF*, the particle still remains at rest. The diagonal *CH* represents such a force both in magnitude and direction.

A single force which can be substituted for two separate forces in this way is termed a *resultant* force.

iv. Other methods of demonstrating the parallelogram of forces.—(*a*) Round two pulleys *A* and *B*, pivoted at the top corners of a board (Fig. 25), pass a fine thread to which two unequal masses are attached. To some convenient place on the thread hang a third mass from a thread as shown. Let the masses come to rest. It will be found that a parallelogram may be constructed, the sides and diagonal of which are proportional to the masses used.

(b) Attach a scale of inches to the edge of a black-board. Obtain two pieces of thin india-rubber cord twenty inches long, and fasten small loops of string to the two ends. Pin one of these loops to the board so that the upper end of the india-rubber cord coincides with the zero of the scale. Attach the upper end of the other india-rubber cord to any convenient point on the board. Bring the two lower ends together and hook on to them a weight (say of 100 grams). Measure off twenty inches from the upper end of each cord. The excess of length in each cord will be proportional to the tension of that cord. Complete the parallelogram with chalk, and show that the diagonal is *vertical* and is equal to the extension of the cord when it hangs vertically by the side of the scale with the weight attached.

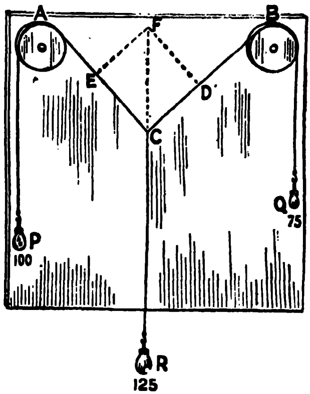

FIG. 25.—Experiment to illustrate the parallelogram of forces.

Graphic representation of forces.—Every force has a certain strength or magnitude, and acts in a certain direction. It is, therefore, possible to represent a force completely by a line, the length of which is made proportional to the magnitude of the force and the direction of which represents the direction in which the force is exerted. If the length of an inch is taken to represent a unit force, then a force of 5 units would be represented by a line 5 inches long, and two forces of 5 and 3 units acting together in the same direction would be represented by a line 8 inches long. If, however, a body were acted upon by a force of 5 units in one direction, and 3 units in the opposite direction, then the effect would be that of a force of 2 units acting in the direction of the force of 5 units; for 3 of the units of this force would be rendered inoperative by the three units acting in the opposite direction.

Parallelogram of forces.—A body can only move in one direction at any given instant, though it may be acted upon by any number of forces. Each force acts with a certain strength and in a certain direction, and, in consequence of their joint action, the body moves with a certain velocity, if it is free to do so. The same velocity could be given to the body by a single

force instead of the separate forces, and the single force which would produce the same effect as the separate forces is called the *resultant* of the forces. When two forces act upon a body at the same time, their resultant can usually be found by means of the parallelogram of forces, which may be expressed thus : *If two forces acting at a point be represented in magnitude and direction by the adjacent sides of a parallelogram, the resultant of these two forces will be represented in magnitude and direction by that diagonal of the parallelogram which passes through this point.*

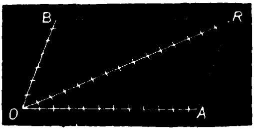

FIG. 26.—Graphic representation of the parallelogram of forces.

Let O represent a material body acted upon by two forces, represented both in magnitude and direction by the lines OB, OA. To find the *resultant* of these two forces, both as regards its amount and direction, complete the parallelogram $OBRA$ and join OR, which will be the resultant required.

Calculation of resultant.—When the two forces of which the resultant is required act at right angles to one another, the calculation is a simple application of a proposition in the first book of Euclid (I. 47). In these circumstances the triangle ORA is right-angled, and Euclid proves that $(OA)^2+(AR)^2=(OR)^2$, and consequently $(OA)^2+(OB)^2=(OR)^2$, from which when OA and OB are known we can calculate OR.

When the directions of the two forces OB and OA are inclined to each other at an angle which is not a right angle, the calculation involves an elementary knowledge of trigonometry. This can be obviated, however, by the simple expedient of what is called the graphical method. This consists in drawing two lines inclined at the angle at which the directions of the forces are inclined, and making them of such lengths that they contain as many units of length as the forces do units of force (Fig. 26). The parallelogram is then completed by drawing AR and BA parallel respectively to OB and OA and joining the diagonal OR, the direction of which will be that of the resultant, and its length will be as many units as there are units of force in the resultant force. It is immaterial what lengths are used to represent the units of force so long as the components and the resultant are measured in the same units.

Resolution of forces.—A single force can be replaced by other forces which will together produce the same effect. Such a substitution is called *resolving* the force, or a *resolution* of the force. The parts into which it is resolved are spoken of as *components*. When this has been done it is clear that we have made the original force become the resultant of certain other forces which have replaced it. Referring back to what has been said about the parallelogram of forces, it will be seen that any single force can have any two components in any directions we like; for by trying, the student will be able to make any straight line become the diagonal of any number of different parallelograms. The most convenient components into which a force can be resolved are those the directions of which are at right angles to each other. In this method of resolution, neither component has any part in the other.

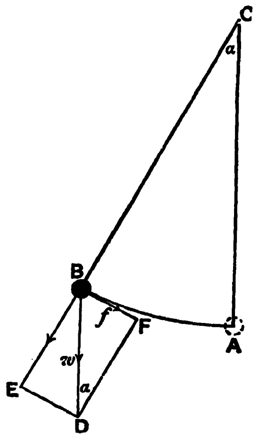

FIG. 27.—Resolution of the force of gravity acting upon a pendulum-bob into two forces *BF*, *BE*.

An interesting example of the resolution of a force into two components at right angles is afforded by a pendulum. Consider a pendulum at any point in its swing, as shown in Fig. 27. The pendulum-bob is pulled downwards in consequence of gravity, that is, the force of attraction between it and the earth, and this vertical force is represented by the line *BD*. The force can, however, be resolved into two forces, one (*f*) due to the inertia of *B*, or the tendency to continue in the direction *BF* and the other represented by *BE*,

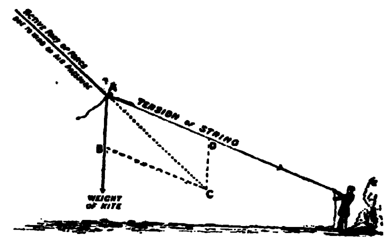

FIG. 28.—Forces acting on a kite at rest in the air.

which has no part in moving the pendulum, and merely causes tension in the string.

A kite at rest in the air affords another example of the principle of the parallelogram of forces (Fig. 28). There are two downward forces—one represented by *AB*, due to the weight of the kite, and the other represented by *AD*, due to the pull of the string. The pressure of the air on the face of the kite can be resolved into two forces, one acting along the face and the other at right angles to it. The latter force is an upward one, and if the kite is at rest it is equal to the resultant *AC* of the two downward forces. If it is greater than the resultant *AC*, the kite rises; if it is less, the kite falls.

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15. MOMENTUM.

i. Collision of equal masses.—Suspend two solid balls of equal mass by the side of one another, so that they just touch when at rest. Place a metre rule on edge on the table under the balls (Fig. 29). Notice the positions of the balls, and then pull each ball to an equal distance from the place where the balls rest, by means of threads held in the two hands. Release the two threads at the same instant. The balls will collide, and if they are of equal mass they will rebound by equal amounts.

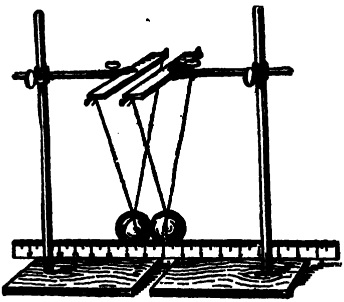

FIG. 29.—Apparatus to illustrate momentum and impact.

ii. Momentum after collision.—Substitute a ball of much smaller mass for one of the balls in the preceding experiment. Pull the two balls away from the position of rest, so that the surfaces which touch one another are at equal distances from this position. Then release the balls simultaneously and observe the rebound. The two balls were at equal distances from their position of rest and are suspended from strings of equal length; therefore their velocities when they meet are equal. The smaller mass has less momentum than the larger before the two meet, but the momentum after collision is the same for each mass; therefore the small mass is given a velocity of rebound as many times greater than the velocity of the large mass as this mass is greater than the smaller one.

Meaning of momentum.—The momentum of a body is the quantity of motion it has, and is equal to the product of its mass and its velocity. Expressed as an equation we have

$$\text{Momentum} = \text{mass} \times \text{velocity}.$$

The unit of momentum is consequently that of a unit of mass moving with a unit of velocity, or if the unit mass be that of the imperial standard pound, the unit of momentum is the quantity of motion in a mass of one pound moving with a velocity of one foot per second. The meaning of momentum will be better grasped after a concrete example.

Suppose a shot fired from a cannon, the momentum generated in both the cannon and the shot will be the same; but since the mass of the cannon is immensely greater than that of the shot, it will be evident that the velocity of the shot must be correspondingly greater than that of the cannon in order that the product of the two quantities may be the same. This we know is the case; the velocity of the "kick" or "recoil" of the cannon is very much less than the velocity with which the shot is sent on its journey.

Or, expressing the fact as an equation,

$$\begin{matrix}\text{mass of}\\ \text{cannon}\end{matrix} \times \begin{matrix}\text{velocity}\\ \text{of recoil}\end{matrix} = \begin{matrix}\text{mass of}\\ \text{shot}\end{matrix} \times \begin{matrix}\text{velocity}\\ \text{of shot.}\end{matrix}$$

16. MOTION IN A CIRCLE.

Uniform angular velocity.—(*a*) As an example of uniform angular velocity, consider the movements of the hands of a clock or watch. The second hand, minute hand, and hour hand move through certain angles upon the dial in each second. These angles differ from one another, but each separate hand has a uniform angular velocity, that is, it moves through equal angles in equal times.

(*b*) Tie a ball to one end of a piece of string; hold the other end of the string in your hand, and swing the ball so that it moves around your hand in a circle. In this case, the tension of the string converts the would-be rectilinear motion of the ball into circular motion.

Conversion of rectilinear into circular motion.—It has already been explained (p. 42) that any object, once set in motion, moves in a straight line unless the action of external force prevents it from doing so. If, therefore, a body is moving in a curve, this is because it is being continually pulled out of its rectilinear path by some force.

Let *Ad* (Fig. 30) represent the string used in Expt. 16, i. (*b*), the ball being at *A*. You will understand from what has been said about the resultants of forces that, if there is a force constantly pulling in the direction of the central point *d*, as well as the tendency to move in a straight line, the ball will not arrive at *O* after the lapse of, say, a second, but at *c*, having travelled along the curved path *Ac*. The short line *Oc* thus represents the pull of the string, or of the central force, at *d*. The same kind of action may be considered always to go on when an object moves in a curve; in other words, any small piece of the curve represents the resultant of two forces—one acting in the direction of a fixed point, and the other being the moving force, or inertia, which tends to make the object keep in a straight line. It can be shown that, in all cases when an object moves around a central point in the manner described, the pull towards the centre, whether it is represented by the tension of a string or by an attraction of some kind—is equal to the mass of the moving body multiplied by the square of the velocity, and divided by the distance from the centre to the object.

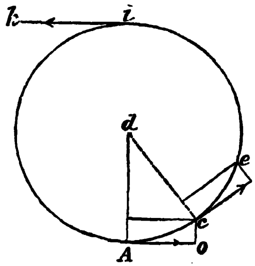

FIG. 30.—Application of the principle of the parallelogram of forces to explain motion in a circle.

An example of motion in a curve around a centre of force, and also of the parallelogram of forces, is afforded by the moon, which moves around the earth in nearly a circular path on account of their attraction for one another. If this attraction of gravitation did not exist, the moon would leave us altogether, just as surely as the ball, the motion of which is represented in Fig. 30, would fly off in the direction *ih* if the string which forced it to move in a circular path were cut when the point *i* was reached.

CHIEF POINTS OF CHAPTER IV.

All matter possesses **inertia.** Inertia is defined by Newton's first law.

Newton's first law of motion.—Every body will continue in its state of rest or of uniform motion in a straight line, unless it is compelled by impressed force to change that state.

Force is that which changes, or tends to change, a body's state of rest or motion. Forces may be completely represented, both in magnitude and direction, by straight lines.

The force of gravitation.—Every particle in nature attracts every other particle with a force which is directly proportional to the product of the masses of the particles and inversely proportional to the square of the distance between them.

$$\text{Gravitational attraction} = \frac{\text{mass} \times \text{mass}}{\text{square of distance between masses}}.$$

Parallelogram of forces.—If two forces acting upon a point are represented in magnitude and direction by the adjacent sides of a parallelogram, their resultant is represented in magnitude and direction by the diagonal which passes through that point.

Resolution of forces.—A single force can be replaced by other forces which will together produce the same effect. Such a substitute is called *resolving* the force, and the parts into which it is resolved are called *components*.

The **momentum** of a body is the quantity of motion it has, and is equal to the product of its mass and its velocity. The total momentum of several moving masses is unaltered by impact.

Angular velocity.—If a body moves in a circle a force must act towards the centre of the circle. If the force suddenly ceases to act the body moves on in a straight line and thus departs from the centre of the circle. Hence curvilinear motion is an effect due to the inertia of the moving body and a force which pulls the body towards the centre of motion.

EXERCISES ON CHAPTER IV.

1. Describe an experiment for demonstrating the principle of the parallelogram of forces to a class.

A nail is driven into a wall and two strings are tied to its head. When the two strings are pulled horizontally and at right angles to one another with forces equal to 6 and 8 lbs. respectively, the nail is dislodged. What force would be needed if the strings were brought together and the nail pulled straight out? Illustrate your answer with a diagram. (P.T. 1897.)

2. Two forces, the magnitudes of which are proportional to the numbers 3 and 4, act on a point at right angles to each other. Draw a parallelogram as nearly to scale as you can to show the direction and magnitude of the resultant, and deduce by measuring your diagram, or in any other way, the magnitude of the resultant. (1897.)

3. What is meant by the parallelogram of forces? Give a diagram to illustrate your answer.

Describe an experiment by means of which the truth of the proposition may be verified. (1897.)

4. Explain what is meant by angular velocity. If two precisely similar bodies travel with the same speed in two circular orbits, of which the radii are in the proportions of 3 to 4—(1) what will be the ratio of the angular velocity about the centre of the larger to that

about the centre of the smaller circle; (2) which body is acted on by the greater force to retain it in its circular path? (1897.)

5. Enunciate Newton's First Law of Motion. Explain what you understand by a natural law.

6. Explain what is meant by the inertia of a material body. Give as many of the results of the possession of this property by a material body as you can.

7. The horizontal and vertical components of a certain force are equal to the weights of 60 lbs. and 144 lbs. respectively. What is the magnitude of the force?

8. State the law of gravitation, and show briefly how its action and the moon's inertia cause the moon to move in a nearly circular path around the earth.

9. A boy flies a kite. What forces are acting on the kite when it is at rest in the air? Draw a diagram to show the direction of each.

10. Four forces act at a point. The first of 10 lbs. acts due north, the second of 15 lbs. due east, the third of 20 lbs. due south, and the fourth of 25 lbs. due west. Find the magnitude and direction of the resultant. (P.T. 1898.)

11. Two spring balances are attached by strings to a ring which is placed round a nail driven into the table, and the balances are stretched in directions at right angles to one another till one indicates a pull of 16 lbs. and the other of 9 lbs. Draw a figure showing the direction and magnitude of a *single* force which would produce the same pressure on the nail as do the *two* forces due to the pulls of the balances.

How would you prove experimentally the correctness of your result? (1899, D.)

12. Explain what is meant by the parallelogram of forces. Forces of respectively 4 and 7 units act on a particle at an angle of 70°. Draw a diagram to illustrate this, and determine by means of it the magnitude of the resultant of these forces. (Junior Oxford Local, 1900.)

13. State the "parallelogram of forces." You are provided with three small spring balances (sometimes called "dynamometers"), a blackboard, chalk, string, etc.; how can you verify the proposition? (Queen's Sch. 1899.)

CHAPTER V.

PARALLEL FORCES. CENTRE OF GRAVITY. THE LEVER.

17. PARALLEL FORCES.

i. **Example of parallel forces.**—Place the ends of a stiff lath or rod of uniform thickness upon two letter balances, or support the rod by hanging each end from a spring balance. Notice the load borne by each balance; then weigh the rod, and so determine the proportion of the load supported at each end.

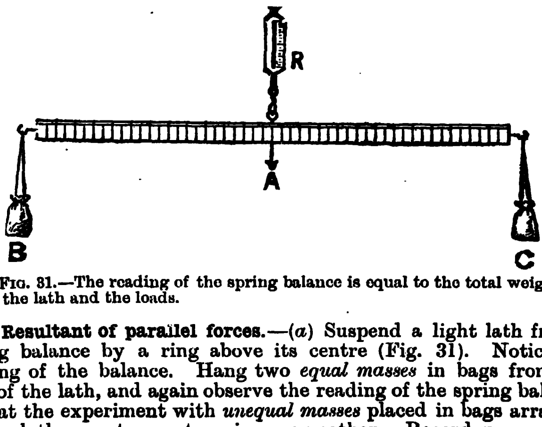

FIG. 31.—The reading of the spring balance is equal to the total weight of the lath and the loads.

ii. **Resultant of parallel forces.**—(*a*) Suspend a light lath from a spring balance by a ring above its centre (Fig. 31). Notice the reading of the balance. Hang two *equal masses* in bags from the ends of the lath, and again observe the reading of the spring balance. Repeat the experiment with *unequal masses* placed in bags arranged on the lath so as to counterpoise one another. Record your results thus:

Mass of lath, A.	Mass, B.	Mass, C.	Total $A+B+C$.	Reading of Spring Balance, R.

By comparing columns 4 and 5 it will be seen that the three downward forces *A*, *B*, and *C*, acting upon the lath, are kept in equilibrium by one upward force *R*.

(*b*) Hang the two masses *B* and *C* together from the middle of the lath suspended from the spring balance. Notice that the reading of the balance is the same as when the two masses are hung from the ends of the lath.

iii. **Conditions of equilibrium of parallel forces.**—To further study accurately the conditions of equilibrium of parallel forces, a method is required which does away with the necessity of considering the mass of the lever. This is obtained as follows:

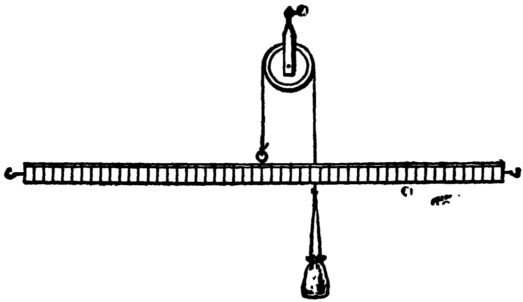

FIG. 32.—Lever suspended for experiments with parallel forces.

(*a*) Suspend the lath by a string which passes over a pulley and has attached to the other end a mass equal to the mass of the lath (Fig. 32). The rod can then move as if it had no mass.

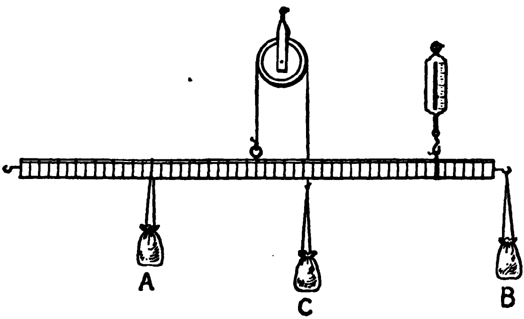

FIG. 33.—Parallel forces in equilibrium.

Upward forces can be applied to it by spring balances, or masses attached to strings passing over pulleys, and downward forces by hanging masses from it.

Attach a spring balance to any convenient point on the lath by passing the hook of the balance through a hole in the lever or by means of thread. Suspend masses A and B from the lath so that they counterpoise one another (Fig. 33). Notice the reading of the spring balance, and the masses used.

Add an additional mass to that used to counterpoise the lath, and also add masses to the lath to restore equilibrium. Record your observations thus:

Mass, A.	Mass, B.	Total downward forces = weights of $A+B$.	Weight of additional Mass, C = upward force.	Downward force − upward force.	Reading of spring balance. (Resultant.)

A comparison of columns 5 and 6 will show that the pull on the balance is equal to the difference of the forces acting downwards and upwards respectively. The reading of the balance shows, in fact, the value of the *net* effect, or the resultant, of all the forces acting upon the lath.

(*b*) Remove the masses, except the one counterpoising the lath. Select a mass, the weight of which is equal to the previous resultant reading of the spring balance. Hang it from the lath, and move it about until the reading of the spring balance is the same as before.

You can thus prove that the direction of the resultant force passes through the fulcrum formed by the supporting hook of the spring balance.

Parallel forces.—It has been seen that the earth exerts a downward pull upon all objects on its surface, and that in consequence of this all things fall to the ground if unsupported. It follows, therefore, that everything which is supported above the earth's surface is constantly being pulled downwards, even though it does not fall. If a beam, for instance, is supported horizontally by resting the ends upon two posts, each particle of it may be regarded as being pulled earthwards by an attractive force. The direction of the pull is everywhere towards the centre of the earth, so for any one spot on the earth's surface we may consider the attractive forces due to gravity to be parallel to one another.

When a stiff lath or rod of uniform thickness rests upon two letter balances, or is supported by hanging each end from a spring balance, the experiment represents on a small scale the

case of a beam referred to before; and by using spring balances it can be proved that the weight supported at its ends is equally divided between the two supports. In other words, the two upward forces exerted by the balances are together equal to the downward force represented by the weight of the beam.

If a load be placed anywhere upon the lath, the balances still show that when the lath is in equilibrium the sum of the upward forces is equal to the sum of the downward forces.

Principle of parallel forces.—The principle of parallel forces demonstrated by the experiments referred to may now be definitely expressed as follows: "*The resultant of a number of parallel forces is numerically equal to the sum of those which act in one direction, less the sum of those which act in the opposite direction.*" In other words, the resultant is equal to the *algebraic* sum of the forces.

If two *equal parallel forces* act in the same direction upon a body, the total force will be obtained (as might be expected) by adding the two individual forces together. In like manner, if two *unequal parallel forces* act in opposite directions the net effect can be found by subtracting the smaller of the two forces from the greater; the direction of the resultant is that of the greater force.

Resultant of parallel forces.—It has been shown experimentally that the resultant of a system of parallel forces is equal in *magnitude* to the algebraic sum of the forces; and that the *direction* of the resultant is the same as that of the greater of the parallel forces. This is illustrated by the experiments (p. 56) in which a mass attached to the end of a string which passes over a pulley and is fixed to the centre of a lath eliminates the mass of the rod; for while the forces due to the loads on the rod act vertically downwards, the resultant, represented by the pull of the spring balance, acts vertically upwards. The *position* which the resultant occupies with reference to the component forces is also shown by the same experiments.

A record of this kind not only shows that the magnitude of the resultant force is equal to the sum of the components, but it also proves that in each case, when the rod is in equilibrium, one force multiplied by its distance from the point of action of the resultant, is equal to the other force multiplied by the other's

distance from the resultant. Or, expressing the result as an equation we have :

$$\begin{matrix}\text{Force on} \\ \text{one side}\end{matrix} \times \begin{matrix}\text{Distance from} \\ \text{resultant}\end{matrix} = \begin{matrix}\text{Force on} \\ \text{other side}\end{matrix} \times \begin{matrix}\text{Distance from} \\ \text{resultant.}\end{matrix}$$

If the component forces are equal, their distances from the resultant will also be equal; and if they are unequal the resultant will always be nearer to the greater force. In other words, a small force is at a large distance from the resultant, and a large force is at a small distance.

18. DETERMINATION OF CENTRES OF GRAVITY.

i. Experimental methods of determining centres of gravity.—(*a*) Procure a disc of sheet cardboard and find by trial the point on which it may be balanced, that is, the centre of gravity of the disc. Make a hole in the card near the edge, and take a plumb-line consisting of a thread with a piece of lead tied at one end and a hook of thin wire at the other. Hang the disc from the hook, and then suspend both as shown in Fig. 34, so that the disc and lead are both suspended and the thread passes over the point of suspension. The thread also passes through the centre of gravity. Do this for various holes in the edge of the disc, and see that in all cases the *vertical line through the point of suspension passes through the centre of gravity.*

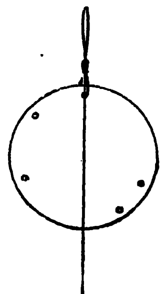

FIG. 34.—Determination of centre of gravity of a disc.

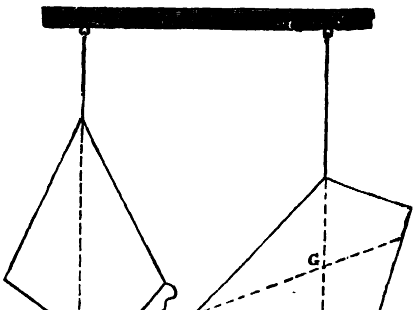

FIG. 35.—A method of determining centre of gravity.

(*b*) Another way to find the centre of gravity of plane figures such as have been described is to tie a string to a plate at each corner. Then hang the plate by one of the strings to a support such

as one of the rings of a retort stand. Allow it to come to rest, and, using a straight edge, draw a chalk mark across the plate in the same straight line with the string as shown by the dotted line in the figure. Now attach the same plate by one of the other threads exactly as before, and again make a mark in continuation of the string. The two chalk marks intersect at a point marked G, Fig. 35. Untie and do the same with another string, the third line passes through the intersection of the first two. Obtain a similar point for each of the other plates. Also determine in the same way a similar point for irregular plates of wood, zinc, or cardboard.

ii. **Centres of gravity of skeleton solids.**—(*a*) Procure a skeleton cube or tetrahedron, and suspend it as in the preceding experiments. Mark the verticals through the point of suspension by light wires attached by wax, and thus find the position of the centre of gravity. The centre of gravity will not be on any of the bars of the skeleton solid used.

(*b*) Find the centre of gravity of an open wickerwork basket, such as a waste-paper basket. To do this, suspend the basket, and hang a plumb-line from the point of suspension. Tie a piece of thread across the basket in the direction of the plumb-line; then suspend the basket from another point, and notice where the plumb-line crosses the thread. The point of intersection, which need not be actually on the framework itself, is the centre of gravity.

Centre of gravity.—Consider a large number of weights, some heavier than others, suspended from a horizontal rod arranged as in Fig. 33. A certain position can be found at which the spring balance has to be attached in order to keep the rod in equilibrium. When the rod is hung from this point the tendency to turn in one direction is counteracted by the tendency to turn in the other, so the rod remains horizontal. The weights may be regarded as parallel forces, and the pull of the spring balance as equal to their resultant. Now consider a stone, or any other object, suspended by a string. Every particle of the stone is being pulled downwards by the force of gravity, as indicated in Fig. 36. The resultant of these parallel forces is represented by the line GF, and the centre of the forces is the point G. The point G, through which the resultant (GF) of the parallel forces due to the weights of the individual particles of the stone passes, is known as the *centre of gravity*. For the stone to be in equilibrium, the string must be attached to a point in the line GF, produced upwards.

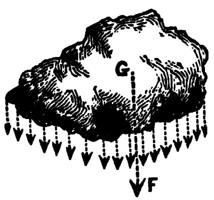

FIG. 36.—Parallel forces due to gravity.

Every material object has a centre of gravity, and the position of this point for a particular object is the same so long as the object retains the same form.

Experimental methods of determining centres of gravity.—The centre of gravity of such geometrical figures as circles, squares, and parallelograms is really the centre of the figures, and can therefore be determined geometrically. In the case of unsymmetrical figures, however, the centre of gravity cannot be so easily found by geometry, and is best determined by experiment.

The experimental method adopted for determining the centre of gravity of any material body depends upon the considerations set forth in the preceding paragraph. The body, the centre of gravity of which is required, is allowed to hang quite freely, either by means of a cord or on a smooth peg, and when it has come to rest a vertical line through the point of support is marked upon it. If a string is employed, this vertical line will be a continuation of the string, and is at once drawn by the help of a ruler. If the body which is being experimented with is hung from a smooth nail, by means of a hole bored in it, the vertical line must be drawn with the help of a plumb-line. The point of support is then shifted and the operation repeated. Since the centre of gravity of the plate is in both straight lines it must be located at their intersection. To increase the accuracy of the results a third or even a fourth line is drawn in the same way.

Plates of all shapes balance about their centres of gravity.—After the centre of gravity of a sheet of metal, or other stiff material, has been determined by hanging it from a support in the manner described in Experiment 18, i., it will be found that if this sheet be so arranged that a pointed upright is immediately under the centre of gravity, the plate will be supported in a horizontal position. This affords a convenient means of checking the correctness of the experiment performed.

Geometrical determination of centres of gravity.—It has been sufficiently explained that the centres of gravity of straight lines, circles, squares, and other regular figures is at their geometrical centres. Hence, the geometrical constructions for determining these central points also locate the position of their centres of gravity.

The centre of gravity of a parallelogram is at the intersection of its diagonals.

The centre of gravity of a triangle is determined by bisecting any two sides and joining the middle points so obtained to the opposite angles. The intersection of the lines so drawn gives the centre of gravity. The centre of gravity is found, by measuring, to be one-third the whole length of the line drawn from the middle point of the side to the opposite angle, away from the side bisected.

We may, in fact, consider a triangular plate as made up of a number of narrow strips of material which decrease in length from the base to the apex. The centre of gravity of each strip is the middle of the strip; hence the line drawn from the apex to the middle of the base passes through each centre of gravity (Fig. 37 *A*). By taking another side as base, a similar line can

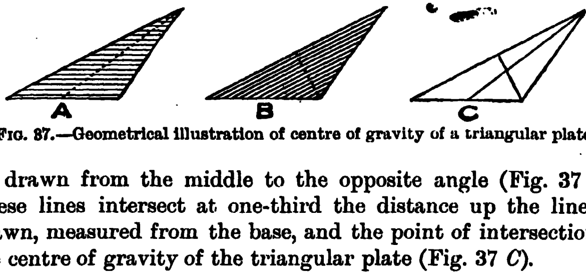

FIG. 37.—Geometrical illustration of centre of gravity of a triangular plate.

be drawn from the middle to the opposite angle (Fig. 37 *B*). These lines intersect at one-third the distance up the line so drawn, measured from the base, and the point of intersection is the centre of gravity of the triangular plate (Fig. 37 *C*).

To find the centre of gravity of a quadrilateral by construction, the plan is to divide it into two triangles by drawing a diagonal. By the method just described the centre of gravity of each triangle is found, and the points so obtained are joined. The centre of gravity of the quadrilateral lies on this line. Repeat the process drawing the other diagonal. Join the centres of gravity of the second pair of triangles, the centre of gravity of the quadrilateral lies on this line. Hence, it is situated at the point of intersection of this line and the first one obtained in the same way.

Centres of gravity of other bodies.—The method of drawing lines across the surface of a thin plate is not practicable in the case of bodies such as blocks or skeleton solids having three dimensions. The experiments described in 18, ii. explain two methods which can be usefully employed in cases of this kind.

The ingenuity of the student will provide other equally suitable plans for particular cases.

19. EQUILIBRIUM.

i. Conditions of equilibrium.—Place upon a square-edged table or board one of the cardboard figures of which you have found the centre of gravity. Gradually slide the figure near the edge until it would just topple over; keeping it in this position, draw a line along the under side of the cardboard where the edge of the table touches it. Then place the cardboard in another position and again mark where the edge of the table touches it when it would just topple over. The intersection of these lines is the centre of gravity, and it will be noticed that the cardboard would just topple over when the centre of gravity falls outside the edge of the table.

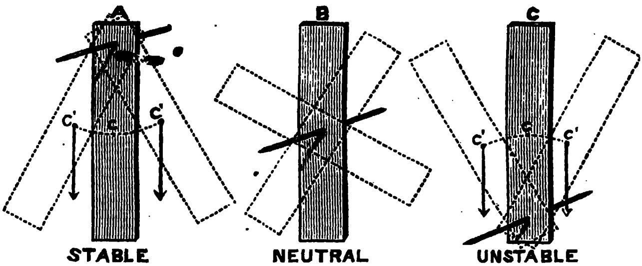

FIG. 38.—Relative positions of centre of gravity and point of support for stable, neutral, and unstable equilibrium.

ii. Stable, neutral, and unstable equilibrium.—Procure an oblong strip of wood or cardboard (Fig. 38). Support the strip as at A by a long pin pushed through it; it is then in stable equilibrium, for the slightest turn either to right or left raises the centre of gravity. When supported as at *B*, the strip is in neutral equilibrium; and when supported as at *C*, it is in unstable equilibrium, for the slightest movement lowers the centre of gravity.

Relation of centre of gravity to base of support.—A circular disc, in which it will be remembered the centre of gravity coincides with the geometrical centre, will not rest upon a table if the centre is beyond the edge of the table, but will topple over. In a similar way, if any plane figure lies flat upon a table the centre of gravity of the figure must be within the edge of the table. The same conditions apply to any object resting upon a support. For an object resting upon a base to be in

equilibrium, a vertical line drawn from the centre of gravity downward must fall within the base. When this vertical line falls outside the base the body topples over.

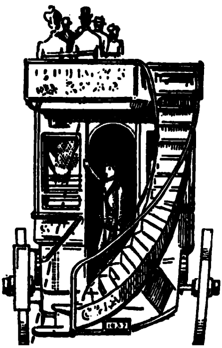

FIG. 39.—If the vertical line from the centre of gravity should fall outside the base of support, the omnibus would topple over.

Consider the case of an omnibus on level ground. The centre of gravity is somewhere inside the omnibus, and a vertical line drawn from it downwards would fall within a line traced around the omnibus upon the ground. But, if the outside of the omnibus is filled with people and the vehicle happens to be running across a sloping road, it might topple over, for a jerk might cause so great a change of position of the centre of gravity as to make the vertical line from the centre fall outside the base of support, and in such a case an accident must happen (Fig. 39).

Equilibrium.—When a body is at rest, all the forces acting upon it balance one another (or, what is the same thing, any force is equal and opposite to the resultant of the remaining forces), and it is said to be in equilibrium. It is in *stable equilibrium* when any turning motion to which it is subjected raises the centre of gravity; in *unstable equilibrium* when a similar movement lowers the centre of gravity, and in *neutral* equilibrium when the height of the centre of gravity is unaffected by such movement. Consequently, if a body in stable equilibrium is disturbed, it returns to its original position; if in unstable equilibrium, it will, if disturbed, fall away from its original position; while if the condition of equilibrium is neutral it will, in similar circumstances, stay where it is placed.

Conditions of stability of suspended and resting objects.—The centre of gravity must in every case be below the point of support for a suspended object to be in equilibrium. The greater the distance between the point of support and the centre of gravity the greater is the tendency to return to the position of equilibrium.

When the centre of gravity and the point of support of a suspended object are close together the equilibrium of the object is easily disturbed. A good balance partly owes its sensitiveness to this condition, the centre of gravity and point of support being designedly brought close together.

It has been shown that in the case of a freely suspended object the centre of gravity is at its lowest point when the object is in equilibrium. Let us see how this applies to a body supported upon a surface below the centre of gravity.

A body is least liable to be upset when the centre of gravity is at a considerable distance from all parts of the edge of the base; for when this is the case the body has to be tilted through a large arc before the centre of gravity falls outside the base.

A funnel standing upon its mouth is an example of a body which cannot be easily overturned on account of the low centre of gravity and its distance from the edge of the base (Fig. 40, A). It is then in stable equilibrium. If the funnel is stood upon the end of the neck it can be easily overturned, because very little movement is required to bring the centre of gravity outside the base. It is then in unstable equilibrium. When the funnel lies upon the table it is in neutral equilibrium, for its centre of gravity cannot then get outside the points of support.

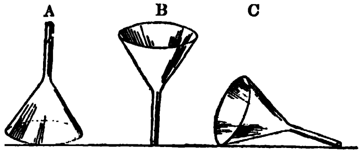

FIG. 40.—A funnel in (A) stable equilibrium, (B) unstable equilibrium, (C) neutral equilibrium.

20. THE LEVER.

i. **Balancing equal masses on a lever.**—(*a*) Make or obtain a lever consisting of a strip of light wood graduated in centimetres, and

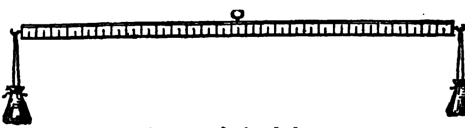

FIG. 41.—A simple lever.

having a thin ring screwed into one edge, above the central point, and a hook screwed into each end (Fig. 41). Hang the lever from a

nail by the middle ring. If it does not exactly balance, plane off a little from the end which sinks, or slightly unscrew the hook at the end which rises above the horizontal, until the lever does set itself horizontally.

Hang two pill-boxes or small linen bags by their strings from the lever, one on each side of the fulcrum or pivot, at equal distances from it. Into one of the bags place a mass of say 50 grams, and find how many grams you must place into the other bag in order to restore equilibrium. Repeat the experiment with the bags at a different distance.

It will always be found that equilibrium is obtained when equal masses are at equal distances from the turning point or fulcrum.

ii. **Principle of moments.**—Place some pieces of lead in each of four linen bags, and adjust by means of shot or small bits of lead until they weigh respectively the same as 50 grams, 100 grams, 200 grams, and 300 grams. Place the 100 gram bag about 12 cm. from the fulcrum of the lever, and balance it with a 50 gram bag on the other side. Record the distance from the fulcrum in each case. Repeat the experiment by balancing 50 grams against 100 grams, 50 grams against 200 grams, 100 grams against 300 grams, and other combinations.

Record your observations in columns as below :—

Left Side of Lever.		Load × Distance.	Right Side of Lever.		Load × Distance.
Load.	Distance from Fulcrum.		Load.	Distance from Fulcrum.	

Compare the numbers in columns 3 and 6, and state in words the law or rule indicated by the results.

The experiments show that there is a definite proportion between the masses on the two sides of a lever, and their distances from the fulcrum. The proportion is :

$$\text{Left load} : \text{Right load} :: \text{Right distance} : \text{Left distance.}$$

Or, expressed in another way, the loads are inversely proportional to their distances from the fulcrum.

The turning effect of any force acting upon a lever, as each load did in the experiment, is termed the *moment* of the force. The comparisons of columns 3 and 6 prove that the *moment* or turning effect is measured by the product of load into distance from the fulcrum.

(*b*) Hang two bags on the same side of the lever at different distances and one bag on the other side. Move the single bag until equilibrium is obtained. Do this several times with the bags in different positions, and compare the sum of the moments of the forces acting on one side with the moment of the force on the other side.

(*c*) Hang a small book or a bag with shot or nails in it on one side of the fulcrum, and the 100 gram bag from the other. Move this bag along the lever until equilibrium is obtained. Then, remembering that

$$\text{Load}_1 \times \begin{matrix}\text{Distance}_1 \\ \text{from fulcrum}\end{matrix} = \text{Load}_2 \times \begin{matrix}\text{Distance}_2 \\ \text{from fulcrum},\end{matrix}$$

calculate the mass of the book or bag of nails. Repeat the experiment, using the 200 gram bag.

In the preceding experiments the fulcrum has been between the forces due to the loads hanging from the lever. The forces may, however, both act on one side of the fulcrum. It is convenient to call one of the forces the effort and the other the resistance.

iii. **Load between effort and fulcrum.**—Suspend the lever from its middle hook as before. Attach a spring balance near one end, and suspend a load from some point between the balance and the fulcrum. The principle of moments applies to this case as to the others, and you will find that

$$\begin{matrix}\text{Reading of} \\ \text{balance}\end{matrix} \times \begin{matrix}\text{Distance of balance} \\ \text{from fulcrum}\end{matrix} = \text{Load} \times \begin{matrix}\text{Distance from} \\ \text{fulcrum.}\end{matrix}$$

The forces acting in this experiment are the same as those called into play when a man lifts the handles of a wheelbarrow having a load in it.

iv. **Effort between load and fulcrum.**—Suspend a load from one end of the lever supported upon the central ring. Attach a spring balance to the lever between the load and the fulcrum, and hold the lever horizontal by means of it. Keeping the balance between the load and the fulcrum, show that whatever the relative distances of the two from the fulcrum, the principle of moments holds good when the lath is kept horizontal. This class of lever is similar, as regards the distribution of forces, to sugar-tongs and ordinary fire-tongs.

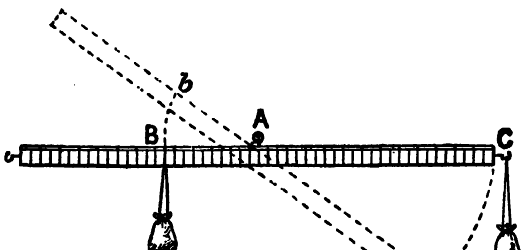

FIG. 42.—Principle of work illustrated by a lever.

v. **The principle of work applied to levers.**—Hang the lever upon a nail in a wall, and when it is horizontal draw a line on the wall along the upper edge. Hang the 100 gram bag from the hook at one end of the lever, and the 300 gram bag on the other side. Move

this bag until it counterpoises the other. Now turn the lever so that the point from which the 300 gram bag is suspended moves through 4 or 5 cm. from *B* to *b* (you can measure this distance by means of compasses). Also measure the distance *Cc* through which the end of the long arm moves. Compare the small with the larger value in each measurement, thus :

$\frac{\text{Length of Long Arm}}{\text{Length of Short Arm}}$.	$\frac{\text{Length of Long Arc, } Cc}{\text{Length of Short Arc, } Bb}$.	$\frac{\text{Large Load}}{\text{Small Load}}$.

Repeat the experiment with different masses.

Machines.—A machine is a contrivance by means of which a given force is made to resist or overcome another force acting in a contrary direction.

What are termed "the mechanical powers" are really simple machines which can be used to overcome resistance. We have now to consider the mechanical principles underlying the action of such simple machines as the lever, the pulley, the inclined plane, and the screw.

The lever.—A lever is a rigid bar which can be freely turned about a fixed point. The *fulcrum* of a lever is the fixed point about which the lever can be turned. The force exerted when using a lever is often described as the *Power* and the body lifted or resistance overcome as the *Weight.* These words are convenient, but they are not correctly used in connection with levers, as their true meanings are confused by so doing. It is better to substitute the word *effort* for power, and *resistance* or *load* for weight. It should be borne in mind, that, so far as mechanical principles are concerned, there is no difference between the power and the weight; both represent forces, and as such they must be considered in the action of levers.

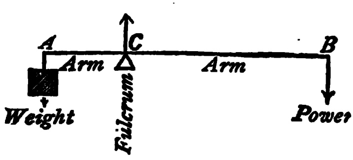

FIG. 43.—Terms used in connection with levers.

The perpendicular distances from the fulcrum to the lines of actions of forces acting upon a lever, are known as the *arms* of the lever. In Fig. 43

the distance AC is the arm of one end at which the "Weight" acts, and BC is the arm of one end at which the "Power" acts.

Classes of levers.—For convenience, levers are divided into three orders or classes, according to the relative positions of the fulcrum and the forces in action. The classes are as follows:

Class I. Fulcrum between resistance and effort. Examples: see-saw, a pump-handle, a balance, a spade used in digging.

Class II. Resistance between effort and fulcrum. Examples: nutcrackers and a wheelbarrow.

Class III. Effort between fulcrum and resistance. Examples: sugar-tongs, ordinary fire-tongs, and the pedal of a grindstone.

These classes are of no real consequence, for the principle underlying the action of all levers is the same.

Principle of the lever.—It is easy to show by experiment, that when a lever is in equilibrium the following equation holds good:

$$\begin{matrix}\text{Mass on} \\ \text{one side}\end{matrix} \times \begin{matrix}\text{Distance} \\ \text{from fulcrum}\end{matrix} = \begin{matrix}\text{Mass on} \\ \text{other side}\end{matrix} \times \begin{matrix}\text{Distance} \\ \text{from fulcrum.}\end{matrix}$$

This principle of moments applies to all levers, so that all that need be remembered when considering the action of a lever of any kind, are the forces working in one direction and their distance from the fulcrum, compared with the forces or resistances which oppose them and the distance of these from the fulcrum.

Moments.—Refer to the diagram (Fig. 44), where F represents the point of support, or fulcrum, of a lath or other straight lever, and M_1 is a larger mass at a distance AF in equilibrium with a smaller mass M_2, at a greater distance FB.

FIG. 44.—To illustrate moments of forces.

The force acting at A is the weight of the mass M_1, acting vertically downwards; and the force at B is the weight of the mass M_2, acting in the same direction. Each force tends to turn the lever in a particular direction, and this turning effect is called the *moment* of the force. The moment of the force acting vertically downwards at A is the product of the force equal to the weight of M_1 into the distance AF, which as the

diagram shows is measured at right angles to the direction in which the force acts. Similarly the moment of the force equal to the weight of the mass M_2, about the point F, is equal to the product of this force and the vertical distance BF.

This is a rule of universal application for taking moments which will have to be used several times later on, and should be well borne in mind.

The moment of a force about any point is the product obtained by multiplying the force by the perpendicular distance between the point and the line of action of the force.

The principle of work.—Work is measured by the product of a force into the distance through which a body is moved in the direction of the force. Now, in every case where such simple machines as the lever, pulley, inclined plane, and screw are concerned, the work done by one set of forces is equal to that done by the other.

Experiment 20, v. has shown that this is true for a lever; for the values obtained in each of the three columns there tabulated are practically the same, thus proving that when a force or effort exerted upon one arm of a lever moves a load or overcomes resistance at the other end, the distance through which the effort is exerted bears the same proportion to the distance through which the resistance is overcome that the resistance itself bears to the effort. In other words, what is gained in force is lost in distance, so that in each case the product of force and distance is the same, whether the lengths of the lever arms, or the arcs through which the ends of the lever move, are taken as the distances.

From the principle of work it follows that if a man, by exerting a force of 10 lbs. on one end of a crowbar, moves 100 lbs. at the other end, he has to exert his effort through 10 inches in order to move the mass one inch. Thus, what is gained in effort has to be made up by distance moved.

CHIEF POINTS OF CHAPTER V.

Parallel forces.—The resultant of a number of parallel forces is numerically equal to the sum of those which act in one direction, less the sum of those which act in the other direction.

Moreover, not only is the magnitude of the resultant of two parallel forces equal to the algebraical sum of the components, but, when there is equilibrium, one force multiplied by its distance from

the point of action of the resultant, is equal to the other force multiplied by the other's distance from the resultant.

Centre of gravity.—The point through which the resultant of the parallel forces, due to the weight of the individual particles of any mass, passes, is known as the centre of gravity of the mass.

The centre of gravity of a body may be determined experimentally by allowing the body to hang quite freely, and when it has come to rest tracing a vertical line through the point of support by means of a straight edge. By repeating the process for a second point of support two such lines are obtained, the intersection of which is the centre of gravity.

Plates of all kinds balance about their centres of gravity.

Positions of centres of gravity.—(*a*) Those of straight lines, circles, squares, and other regular figures, are at their geometrical centres.

(*b*) That of a parallelogram is at the intersection of its diagonals.

(*c*) That of a triangle is on the line drawn from one of its angles to the middle point of its opposite side, and at a distance of one-third of this line's length from that side of the triangle.

Equilibrium.—In a body in equilibrium all forces acting upon it balance one another.

It is in *stable equilibrium* when any turning motion to which it is subjected raises its centre of gravity.

It is in *unstable equilibrium* when any turning motion lowers its centre of gravity.

It is in *neutral equilibrium* when the height of the centre of gravity is unaffected by such movement.

A machine is a contrivance by means of which a given force is made to resist or overcome another force acting in a contrary direction.

A lever is a rigid bar which can be freely turned about a fixed point (the *fulcrum*). The force exerted when using a lever is called the *effort*, and the body lifted, or force overcome, the *resistance*.

Classes of levers.—1. Fulcrum is between resistance and effort. Examples: see-saw, pump-handle, balance, crow-bar.

2. Resistance is between effort and fulcrum. Examples: nutcrakers, wheel-barrow, and boat oar.

3. Effort between resistance and fulcrum. Example: pair of tongs.

Principle of lever.—

$$\begin{matrix}\text{Mass on} \\ \text{one side}\end{matrix} \times \begin{matrix}\text{Distance from} \\ \text{fulcrum}\end{matrix} = \begin{matrix}\text{Mass on} \\ \text{other side}\end{matrix} \times \begin{matrix}\text{Distance from} \\ \text{fulcrum.}\end{matrix}$$

Moments.—The turning effect of a force is called the *moment of the force*. The moment of a force about any point is the product obtained by multiplying the force by the perpendicular distance between the point and the line of action of the force.

EXERCISES ON CHAPTER V.

1. Describe the principle of the action of a simple lever.

A stiff wooden rod, six feet long, and so light that its weight may be neglected, lies upon a table with one end projecting four feet over

the edge. Upon the end of the rod lying on the table a weight of 8 lbs. is placed. What weight must be placed upon the other end so as just to tip the rod? (P.T. 1897.)

2. A uniform rod is pivoted at its middle point, and a weight of 20 grams is attached at a point 25 centimetres from the fulcrum. To what point on the rod must a weight of 15 grams be attached in order that the rod may balance in a horizontal position? (1898.)

3. Give a simple illustration of each of two different kinds of lever. (1896.)

4. State briefly why it is that a lever may be used so that the force exerted by one end of it is greater than the force exerted upon the other end.

5. What is meant by the "principle of work"? Apply the principle to the case of a lever.

6. What is a lever? What is the "fulcrum" of a lever?

Name four or five levers in common use, and say where the fulcrum of each may be. (P.T. 1898.)

7. Two forces, P and Q, act upon a body, If P acted alone it would, in two seconds, produce in the body a velocity of 10 feet per second, while if Q acted alone it would in three seconds produce in the body a velocity of 18 feet per second. What velocities will P and Q produce in one second when acting together if the directions in which they tend to move the body are—(1) inclined; (2) directly opposed? (1897.)

8. What is meant by the resultant of two forces?

Describe an experiment to prove that the resultant of two parallel forces is equal to the algebraical sum of the forces. (1899.)

9. How would you determine the centre of gravity of an iron hoop made by joining together two semicircles, one thicker than the other? Explain how the observations could be used to find out which was the thicker half of the hoop. (P.T. 1897.)

10. How would you determine experimentally the centre of gravity of a sheet of cardboard of irregular shape? (1898.)

11. When is a body said to be in equilibrium? Distinguish between stable, unstable, and neutral equilibrium. What is the condition which determines the nature of the equilibrium?

12. A piece of cardboard, nine inches long and six inches broad, is divided into six equal squares by means of a ruler and pencil. One of the two squares that are not corner squares is cut away with a penknife. Find the centre of gravity of the remaining piece of cardboard. (P.T. 1898.)

13. A man with a bucket in one hand, stands with his feet close together. Why is it that in order to preserve his balance the man has to stand with his body leaning to one side? Illustrate your answer by a sketch. (1899.)

14. What is meant by the moment of a force? Show, by means of an example, how to find the resultant of several parallel forces by the principle of moments.

15. The lever of a common pump is seldom straight, but is bent at an angle at the fulcrum. Often, also, there is a heavy ball of iron affixed to the end of the handle. What advantages are there in these features of construction? (London Matriculation, 1899.)

16. A solid hemisphere made of uniform material is placed with any part of its curved surface upon a horizontal plane. Show that, however thus placed, it will always tend to a position of stable equilibrium with its flat surface horizontal and uppermost. What other positions of equilibrium are there? Which of them are stable and which unstable? (London Matriculation, June, 1900.)

17. Being given an object like a sugar-bowl, how would you propose to find experimentally the position of its centre of gravity? (London Matriculation, January, 1900.)

18. A lever, two feet long, has a force equal to the weight of 10 lbs. acting at one end, 18 inches from the fulcrum. What is the greatest weight it will support at the other end?

19. How do you define the moment of a force about a point, and how can you apply the principle of moments to find the resultant of parallel forces?

Two men A and B support the ends of a wooden beam six feet long and weighing 1 cwt. A weight of $2\frac{1}{4}$ cwt. hangs from the beam at a distance of 2 ft. from A. What are the total weights supported by A and B respectively? (Junior Oxford Local, 1900.)

CHAPTER VI.

THE PULLEY, THE INCLINED PLANE, AND THE SCREW.

21. THE SIMPLE PULLEY.

i. **Single fixed pulley.**—Hang a pulley from a stand or nail, and over the wheel or sheaf pass a fine flexible cord having a loop tied at each end. Connect a light tray or bag with each end of the cord. Put a mass in one of the trays, and then gradually place bits of lead or small nails in the other until the first tray moves (Fig. 45). When this happens, take each of the trays and find the mass of each with its contents. Repeat the experiment with different masses, and record your results in parallel columns.

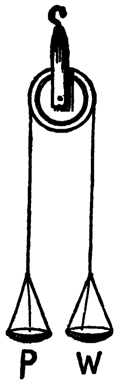

FIG. 45.—A single fixed pulley.

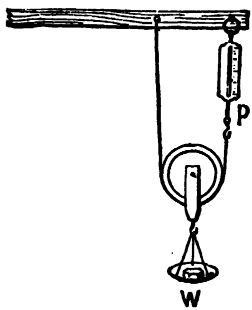

FIG. 46.—A single movable pulley.

The two trays with their contents will be found to have very nearly the same mass, but not exactly, for in order to move the tray W, the mass P must be a little greater than that of W, as the friction of the pulley upon its axle has to be overcome.

ii. **Tension in string supporting movable pulley.**—(*a*) Place a weight in one of the trays previously used, and suspend the tray and a pulley together from a spring balance. Record the reading of the

balance. Now arrange the pulley and balance as shown in Fig. 46, and again record the reading.

Load, W.	Reading of Spring Balance, P.	Ratio $\frac{P}{W}$.

It will be noticed that P is only $\frac{1}{2}W$ (roughly) in every case; in other words, the tension in a cord supporting a movable pulley having a mass hung from it is equal to one-half the total mass supported.

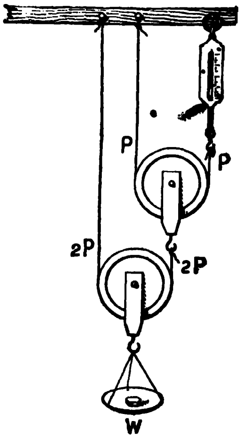

FIG. 47.—Two movable pulleys.

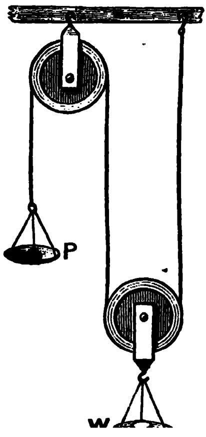

FIG. 48.—One fixed and one movable pulley.

(b) Hang the tray with weights in it, together with two pulleys, from a spring balance, as before, and observe the reading. Then arrange the pulleys in connection with the spring balance as shown in Fig. 47, and again observe the reading. Tabulate your observations.

Load W (pulleys and weights).	Reading of Spring Balance, P.	Ratio $\frac{P}{W}$.

In this case, that is, with two movable pulleys, it will be noticed that the force required to support the pulleys and load is less in proportion than when one pulley was used.

Another way to determine the advantage of using movable pulleys is to pass the free end of the cord over a fixed pulley, as in the following experiment, instead of connecting it with a spring balance.

iii. **Mechanical advantage.**—Arrange one fixed and one movable pulley as in Fig. 48. Place various masses in succession in the tray *W*, suspended from the movable pulley, and add lead or shot to the tray *P* until *W* begins to move. Then disconnect the pulleys and find the mass of *P* and its contents, and the total mass of *W* and the movable pulley. Tabulate your observations thus:

Total Mass lifted (W+pulley).	Moving Force, P.	$\frac{\text{Total Mass}}{\text{Moving Force}}$.

iv. **Principle of work applied to pulleys.**—When the load and moving force are in equilibrium in the preceding experiment, mark the height of the bottom of each tray from the table. Then move the tray *P* through a certain distance, and observe how much the tray *W* is moved. It will be found that:

$$P \times \text{distance moved} = W \times \text{distance moved.}$$

The Pulley.—A pulley is a wheel having a grooved rim, and capable of rotating about an axis through its centre. The frame which holds the pulley is called the block.

Most satisfactory experimental results are obtained by using pulleys made of aluminium, which can now be obtained at a small cost. In pulleys of this sort the errors due to friction are almost eliminated. Your experiments have shown you that although a movable pulley, that is one which can move up and down, reduces the effort which has to be exerted to support a given mass, a fixed pulley is of no advantage in that respect. The number of times that the resistance overcome or mass moved exceeds the effort exerted, or moving force, is known as the *mechanical advantage* of a machine.

The way in which pulleys enable resistance to be advantageously overcome is demonstrated by the experiments you have performed to learn the uses of single fixed pulleys and single movable pulleys.

Use of a single fixed pulley.—With a single *fixed* pulley, no mechanical advantage is obtained. All that the pulley does is *to change the direction of the pull*; if one of the loads, for instance, is pulled down, the other rises. The pulley thus acts in the same way as a lever balanced at its centre; the distance from the centre to the circumference, in other words, the radius of the pulley, being regarded as one arm of the lever. A pulley having a radius of three inches has therefore an equivalent lever-arm three times as great as one with a radius of one inch.

A pulley supported as in Fig. 49 may be considered as an example of the action of parallel forces. The forces $W+W+$the weight of the pulley, acting downwards, are kept in equilibrium by the single force T acting upwards. If a single mass, the weight of which is equal to $W+W+$pulley, were hung from the cord, it would produce the same tension as the three forces, that is it would be their resultant.

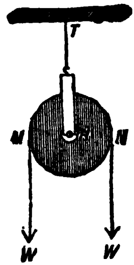

FIG. 49.—Parallel forces acting on a pulley.

Use of a single movable pulley.—The fixed pulley, as has been already seen, is of no advantage in reducing the force required to raise a mass; the advantage gained is derived from the use of a movable pulley. For instance, in the case of the experiments represented in Figs. 46-48, one half of the mass W is supported by the part of the string hooked to the beam, and the other half is supported by the part of the string which goes around the fixed pulley to the mass marked P, or to the spring balance. There are several different combinations of pulleys, but the principle exemplified by the foregoing experiments, namely, that every movable pulley reduces by one-half the effort required to support or raise the mass below it, is utilised in them all.

The principle of work applied to pulleys.—With pulleys, as with levers, there is neither loss nor gain of work. If, in any combination of pulleys, a force of 10 lbs.' wt. balances a force of 120 lbs.' wt.—the mechanical advantage, resistance ÷ effort, thus being 12—the effort will have to be exerted through twelve feet in order to move the resistance through one foot. For it is an invariable rule that

$$\text{Effort} \times \begin{array}{c}\text{the distance through}\\ \text{which it acts}\end{array} = \text{Resistance} \times \text{Distance moved.}$$

The mechanical advantage of any system of pulleys can therefore be determined (1) by finding the relation between the load moved and the force exerted, or (2) by comparing the distance through which the force is exerted with that through which the load moves.

22. THE INCLINED PLANE.

i. **Principle of the inclined plane.**—Arrange a hinged board with a weight attached by elastic to the free end. Show that the tension is less when the weight rests on the board than when it is suspended freely.

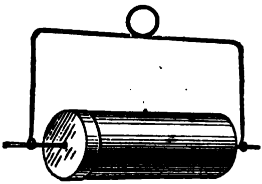

Fig. 50.—Roller for inclined plane.

ii. **Relation between effort and load, when the effort is exerted parallel to the plane.**—(*a*) Obtain a large pill box or small canister, and run a knitting needle through it from end to end to form an axle (Fig. 50). Fit a wire handle upon the axle, and attach to it a spring balance or an elastic cord.

Place some shot or sand in the roller thus constructed. Pull the roller along the hinged board used, with the board horizontal, and notice how much the cord or spring balance is stretched. Now tilt the board slightly and pull the roller up it, as in Fig. 51, taking care that the direction in which you pull is parallel to the slope of the board. Observe the amount by which the cord stretches as you pull up the roller. Then hold the cord vertically and find what load will stretch it by the same amount. The weight found represents the force used. Weigh the roller and shot and so obtain the mass moved. Afterwards measure the length *AC* and the height *AB*, and find the relation between them as below:

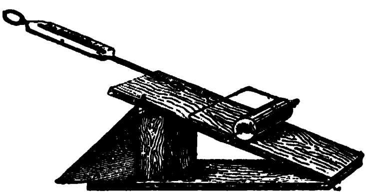

Fig. 51.—Force acting parallel to an inclined plane.

$$\frac{\text{Mass moved}}{\text{Force exerted}} = \frac{\ldots\ldots}{\ldots\ldots} =$$

$$\frac{\text{Length of plane}}{\text{Height of plane}} = \frac{\ldots\ldots}{\ldots\ldots} =$$

Are the two results approximately the same? If so, you may conclude that the mechanical advantage of an inclined plane, when the force exerted acts parallel to the plane, is equal to the length of the plane divided by the height.

In measuring an inclined plane, any vertical line such as AB (Fig. 52) can be taken as the height, provided that the two other sides of the triangle which it forms are taken as the length and base of the plane.

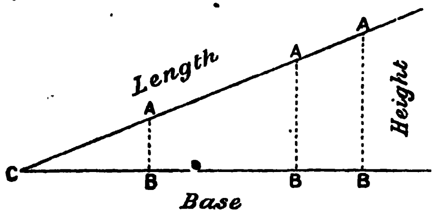

FIG. 52.—Height, length, and base of an inclined plane.

(*b*) Repeat the experiment with the inclined plane, that is the board, tilted at different angles, and with different amounts of shot in the roller. Record in columns as below:

Load.	Force.	Height of Plane.	Length of Plane.	$\frac{\text{Load}}{\text{Force}}$.	$\frac{\text{Length}}{\text{Height}}$.

The experiments will show that, in the case of the inclined plane, when the power acts parallel to the plane

$$\text{Mechanical advantage} = \frac{\text{Length of plane}}{\text{Height}}.$$

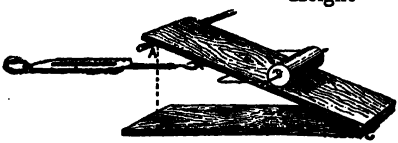

FIG. 53.—Force acting horizontally on an inclined plane.

iii. **Relation between effort and load, when the effort acts horizontally.**—(*a*) Arrange the roller as shown in Fig. 53. Keeping the india-rubber cord horizontal, pull the roller up the inclined plane. Observe the stretch of the india-rubber, and find what load will produce the same amount; or if you are using a spring-balance, observe the reading under these conditions. Then weigh the roller with the wire handle. Measure the lengths of BC and AC.

$$\text{Mechanical advantage} = \frac{\text{Mass moved}}{\text{Force exerted}} = \frac{\cdot\ \cdot\ \cdot\ \cdot}{\cdot\ \cdot\ \cdot\ \cdot} =$$

$$\frac{\text{Base of plane}}{\text{Height of plane}} = \frac{\cdot\ \cdot\ \cdot\ \cdot}{\cdot\ \cdot\ \cdot\ \cdot} =$$

Do the results bear out the statement that when a mass is being pulled up an inclined plane by a force which acts horizontally, the ratio which the force bears to the mass, in other words, the mechanical advantage, is equal to the base of the plane divided by the height?

(*b*) Repeat the preceding experiment with the board tilted at different angles. Record your results as below:

Load.	Force exerted.	Height of Plane.	Base of Plane.	$\frac{\text{Load}}{\text{Force}}$.	$\frac{\text{Base}}{\text{Height}}$.

The inclined plane.—A plane in mechanics is a rigid flat surface, and an inclined plane is one that makes an angle with the horizon.

The reason for the decrease of tension in an elastic cord attached to a mass resting on an inclined board, compared with the tension when the mass hangs freely, will be best understood by applying the principle of the parallelogram of forces to the inclined plane. Suppose an object O (Fig. 54) is kept in position upon a smooth inclined plane by a force acting up the plane, as in Expt. 22, ii. (*a*). The object is acted upon by three forces, namely, W, due to its weight, acting vertically downwards, P, the force exerted up the plane, R the reaction of the plane. The weight acting downwards is thus kept in equilibrium by the two forces R and P acting upwards. The last-named force represents the effort exerted, and being one of two it is evidently less than the weight whenever the object rests upon the plane.

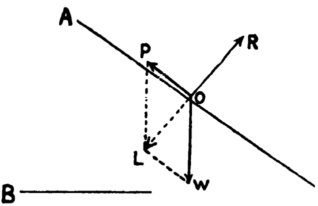

FIG. 54.—Parallelogram of forces applied to an inclined plane.

Let OP and OW be respectively drawn of lengths proportional to the force exerted up the plane, and the weight of the object O. Complete the parallelogram $PLWO$, and draw the diagonal OL. This parallelogram represents graphically in magnitude and direction the forces in equilibrium when a body of definite

weight is kept in position upon a smooth inclined plane, by a force acting up the plane. If the sustaining force acts horizontally, the parallelogram shown in Fig. 55 represents the forces concerned, OP representing the force exerted, OW the weight, and OL the pressure on the plane.

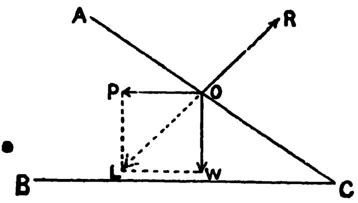

FIG. 55.—Parallelogram of forces applied to an inclined plane.

Advantage of the inclined plane.—When a load is kept at rest upon an inclined plane by means of a force acting along the length of the plane, or horizontally, the effort, or force used, is always less than the load, and the proportion which one bears to the other differs with different inclinations of the plane. There is a definite relation between this proportion and the slope of the plane on which the load moves. When the force is exerted parallel to the plane, this proportion is as follows:

Load moved	:	Force exerted	::	Length of plane	:	Height of plane.

This rule can also be deduced from the principle of work. If the roller starts from C (Fig. 51) and moves to A, it is lifted through the vertical height AB. For this to take place, the force has to be exerted through a distance equal to the length of the plane AC. Therefore

$$\frac{\text{Load}}{\text{Force}}=\frac{\text{Distance through which the force is exerted}}{\text{Vertical distance through which load is lifted}}.$$

Or, Load × height of plane
= Force × length of plane.

When the effort acts horizontally, the ratio which it bears to the load is in the proportion which the *base* of the plane BC bears to the height AB.

A *wedge* can be considered to be two inclined planes base to base, this double plane being pushed forward by a force exerted parallel to the direction of the base (Fig. 56).

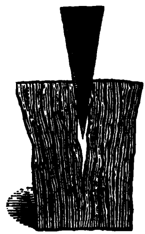

FIG. 56.

23. THE SCREW.

i. **Screw and nut.**—Obtain a large screw, or bolt, and a nut into which it fits (Fig. 57). Scratch a line along the tops of the screw thread from one end of the screw to the other in the direction of the axis.

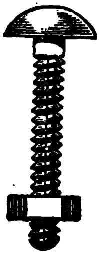

FIG. 57.—Screw and nut.

Place your rule along the screw and see how many of the spaces between successive threads are equal to the length of an inch. You can thus find the distance between two successive threads. Another way is to measure the length between, say, 11 threads, and divide this by 10 to find the distance from one thread to the next. Record this distance in your note-book.

Put the bolt upon the screw and turn it until it reaches one of the marks scratched upon the thread. Make a line upon the bolt at the point where the scratched thread touches it. Turn the screw, and notice that one complete turn brings another mark to the side of the line upon the bolt.

You thus see that one complete turn advances the screw by an amount equal to the distance between two successive threads. You know what this distance is, and can therefore write down the distance through which the screw advances for any number of turns.

Find (i) by calculation, using the value you have found for the distance between successive threads, (ii) by direct measurement, the amount of advance of the screw with reference to the nut when it is given 7, 8½, 10, 11½, and 14 turns.

To understand the principle utilised in the preceding exercise, a model screw thread should be constructed as follows.

ii. **Construction of a model screw thread.**—Cut out of paper a right-angled triangle such as *ABC* (Fig. 58) and wind it round a pencil. The slant side of the triangle forms a spiral upon the

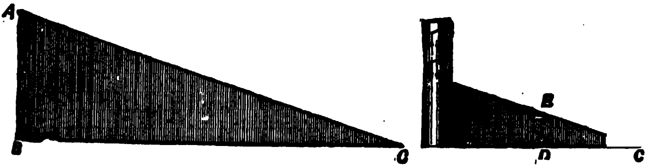

FIG. 58.—Formation of a screw thread by the slope side of an inclined plane.

pencil, similar in appearance to the thread of a screw. If the inclination of the triangle is small, the threads appear close together, and if it is large they occur farther apart. Mark where the end *C* of the paper touches the base of the triangle and draw a line *DE*, perpendicular to the base, from this point to the slant side. The small triangle *CDE* thus formed is similar to the large one, and it represents one turn of the screw thread.

Principle of the screw.—Comparing the screw construction with an inclined plane, it will be seen that

Height of inclined plane represents distance between threads,
Base of " " " circumference of screw.

The angle of inclination of the inclined plane is represented by the angle *ECD* (Fig. 58), and this determines the *pitch* of the screw.

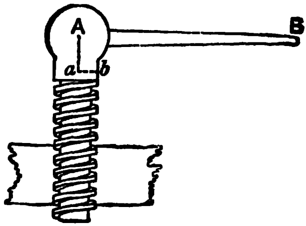

FIG. 59.—A screw turned by a lever.

In considering the use of a screw, the resistance to be overcome can be regarded as a load upon an inclined plane. With a screw such as is shown in Fig. 59 the force acts in a direction parallel to the base of the plane. Under this condition

Load : Force :: Base of plane : Height of plane.

Or, expressing the proportion in the terms which apply to screws :

$$\text{Resistance} : \text{Effort} :: \begin{array}{c}\text{Circumference}\\ \text{of screw}\end{array} : \begin{array}{c}\text{Distance between}\\ \text{successive threads.}\end{array}$$

When force is applied at *B*, leverage is gained in the proportion of *AB* to *ab*, and so further mechanical advantage is obtained on this account. But, in order to advance the screw by a distance equal to that between two successive threads, the end of the handle *B* has to be turned through a complete circumference. This fact can be used to deduce the mechanical advantage of a screw from the principle of work.

For since

$$\text{Effort} \times \begin{array}{c}\text{Distance through}\\ \text{which it acts}\end{array} = \text{Resistance} \times \begin{array}{c}\text{Distance through}\\ \text{which it is over-}\\ \text{come}\end{array}$$

we have

$$\text{Effort} \times \begin{array}{c}\text{Circumference of}\\ \text{circle described}\\ \text{by it}\end{array} = \text{Resistance} \times \begin{array}{c}\text{Distance between}\\ \text{two successive}\\ \text{threads.}\end{array}$$

Hence the mechanical advantage, or resistance ÷ effort, is equal to

$$\frac{\text{Circumference of circle described by effort}}{\text{Distance between two successive threads}}.$$

CHIEF POINTS OF CHAPTER VI.

The **pulley** is a wheel having a grooved rim, and capable of rotating about an axis through its centre. The frame which holds the pulley is called the *block*.

The number of times that the resistance overcome exceeds the effort exerted is known as the *mechanical advantage of a machine*.

A single fixed pulley gives no mechanical advantage. All that it does is to change the direction of the pull.

A single movable pulley reduces by one half the effort required to raise a given load.

Principle of work applied to pulleys:

$$\text{Effort} \times \begin{array}{c}\text{the distance through} \\ \text{which it acts}\end{array} = \text{Resistance} \times \text{Distance moved.}$$

The inclined plane is a rigid flat surface which makes an angle with the horizon.

Advantage of the inclined plane.—When the force is exerted parallel to the plane,

Load moved : Force exerted : : Length of plane : Height of plane,

or

$$\frac{\text{Load}}{\text{Force}} = \frac{\text{Distance through which force is exerted}}{\text{Vertical distance through which load is lifted}}.$$

Therefore,

$$\text{Force} \times \begin{array}{c}\text{Distance through which} \\ \text{it is exerted}\end{array} = \text{Load} \times \begin{array}{c}\text{Vertical distance} \\ \text{moved.}\end{array}$$

A wedge can be considered as two inclined planes base to base. This double plane is pushed forward by a force exerted parallel to the direction of the base.

Principle of the screw.—The distance between successive threads represents the height of an inclined plane: the circumference of the screw represents the base of an inclined plane. Moreover, as

Load : Force : : Base of Plane : Height of plane;

Resistance : Effort : : Circumference of screw :
Distance between successive threads;

$$\frac{\text{Resistance}}{\text{Effort}} = \frac{\text{Circumference of arc described by power arm}}{\text{Distance between successive threads}}.$$

EXERCISES ON CHAPTER VI.

1. State the principle of the action of a simple pulley.

How would you show that the strain or tension in a cord supporting a pulley is equal to half the weight hanging from the pulley? (P.T. 1897.)

2. One end of a piece of india-rubber cord is pinned to a drawing-board longer than the cord; to the other end a weight is attached.

The drawing-board is slightly inclined by lifting the edge to which the india-rubber is pinned. What effect has this upon the india-rubber?

Is the effect increased or decreased when the inclination is made greater? Show, by means of a diagram, the direction of the forces which act upon the weight when it rests upon the inclined drawing-board. (P.T. 1897.)

3. Describe the action of a single movable pulley in decreasing the force which has to be exerted to support a given mass.

4. Show, by means of the parallelogram of forces, the action of an inclined plane when the effort is exerted parallel to the plane.

5. A pulley is hung from a beam and a cord is passed round the groove. A mass of one pound is hung from one end of the cord. What mass must be put at the other end of the cord to produce equilibrium?

6. Explain by reference to an inclined plane what you understand by the "mechanical advantage" of a machine.

7. Give in a few words the principle of the screw. On what does the ratio of the resistance overcome to the effort exerted depend?

8. Explain how a weight, a pulley, and a chain can be arranged so as to make a door shut when it is let go. Draw a diagram. What forces has the weight to overcome as it shuts the door? (P.T. 1898.)

9. A penny lies at rest on a sloping desk. What forces are acting on it? Draw a diagram showing clearly the direction of each. (P.T. 1898.)

10. What must be the inclination of an inclined plane so that a given force, whether it acts horizontally or parallel to the length of the plane, will support the same mass? (This question should be answered by means of diagrams.)

CHAPTER VII.

FLUID PRESSURE.

24. PRESSURE OF LIQUIDS.

i. **Liquids communicate pressure equally in all directions.**—Make a hole in an india-rubber ball. Fill the ball with water by holding it under water and squeezing the air out. Prick a number of small holes in the ball by means of a long pin. Place a finger over the large hole and squeeze the ball; the water will spurt out of each hole straight from the centre of the ball, thus showing that the pressure has been transmitted equally in all directions.

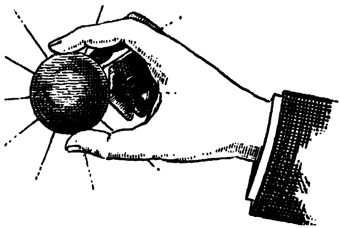

FIG. 60.—Liquids transmit pressure equally in all directions.

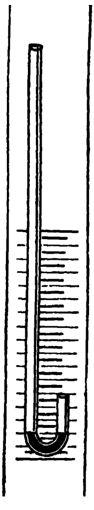

FIG. 61.—Arrangement for determining the pressure of water at different depths.

ii. **Relation between pressure of liquid and depth.**—(*a*) Bend a piece of glass tubing, as shown in Fig. 61, the long arm having a length of about 40 cm. Mount the tube firmly upon a strip of wood having half centimetre divisions marked upon it, or upon a metric scale. Pour enough mercury into the tube to just fill the bend. Notice that the level of the mercury is the same in the two arms of the tube.

Lower the frame into a tall jar of water so that the open end of the short arm of the tubes is 10 cm. below the surface of the water. Notice the difference of level of the mercury in the two arms, and record it.

Lower the tubes an additional 10 cm. and observe the effect. Then lower the frame as far as it will go, and again note the difference between the height of the mercury in two arms. Record your observations in parallel columns thus:

Depth of Mercury Surface below Water.	Difference of Level of Mercury produced by Water Pressure.

(*b*) Repeat the preceding exercise, using turpentine, or a strong solution of salt, or any other convenient transparent liquid instead of water, and record your results as before.

(*c*) To show that the pressure in any particular liquid depends only upon the depth, mount two tubes upon a frame, as shown in Fig. 62—one with the lower opening turned upwards, and another with the opening pointing sideways. Pour the same quantity of mercury in the tubes. Arrange the tubes so that the lower openings are at the same level. Lower the frame, a few centimetres at a time, into water, and observe the difference of level of mercury produced in each tube. Record in columns as below:

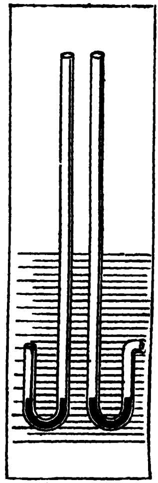

FIG. 62.—Arrangement for showing that pressure in any particular liquid depends only on depth.

Depth of End below Surface of Water.	Rise of Mercury in *A*	Rise of Mercury in *B*.

(*d*) Immerse the frame of tubes to any level which causes the mercury to rise by a clearly-marked amount. Turn the frame to face in various directions, keeping it at the same depth, and notice that the pressure, as indicated by the rise of mercury, is the same in all directions at any particular depth. Test this for several depths.

iii. **Relation between pressure of liquid and area.**—(*a*) Obtain two tubes of brass, glass, or varnished cardboard, each about 15 cm. long, but one being about twice the diameter of the other. Close one end of each tube by means of a disc of the same diameter fixed upon it, or by a cork. Determine the area of the bottom of each tube, and find the proportion which one bears to the other.

Make a mark upon each tube at the same distance—say 10 cm.—from the closed end. Float the tubes in a jar of water, and add sufficient shot to each to immerse them to the marks already made. The lengths immersed are then the same.

Take out each tube, wipe it dry, and weigh it with the shot it contains. Find the proportion of one weight to the other. Record thus:

$$\frac{\text{Area of end of large tube}}{\text{Area of end of small tube}} = \frac{\dots\dots}{\dots\dots} = \dots\dots;$$

$$\frac{\text{Weight of large tube and shot}}{\text{Weight of small tube and shot}} = \frac{\dots\dots}{\dots\dots} = \dots\dots.$$

As the bottom of each tube was at the same distance below the surface of the water, the pressure due to depth was the same. This pressure or force has been found to act in all directions, and it urges the tubes upwards. Though the *pressure* at any given depth is constant the *total pressure* is dependent upon area.

iv. **Pressure of liquid independent of the form and volume of containing vessel.**—(*a*) Bend a short length of fairly wide glass tubing into a U-form, as shown in Fig. 63. Fit a short piece of india-rubber tubing over one of the arms. Pour sufficient mercury into the tube to cover the bend. Connect a straight piece of glass tubing with the india-rubber, and introduce water into it. Measure the difference of height of the mercury in the two arms produced by the pressure of the column of water. Substitute a funnel, or a curved tube for the straight one, and fill it to the same height with water. Measure again the difference of height of the mercury in the two arms of the U-tube. The pressure upon the mercury depends merely upon the *head* or height of liquid.

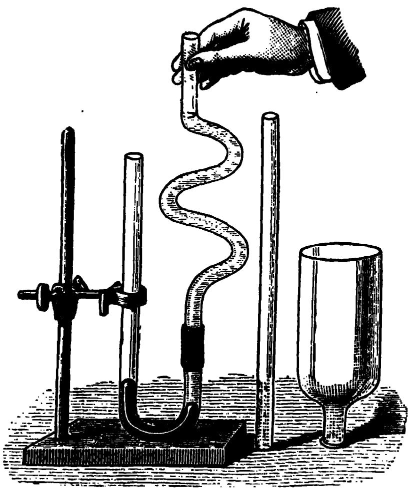

FIG. 63.—Experiment to show that liquid pressure is independent of the form of containing vessel.

v. **Upward pressure of liquid.**—(*a*) Procure a piece of wide glass tubing, or a straight lamp glass, having one end flat. If stiff leather is available, cut out a disc of slightly larger diameter than that of the glass, and pass a knotted thread through its centre. If a

leathern disc cannot be obtained, make a disc of wood or stiff cardboard. Hold the disc tightly upon the flat end of the glass by means of the thread, and while doing so lower the glass into a jar of water (Fig. 64). When the end of the glass with the disc upon it is a few inches below the surface of the water, the thread can be released and the disc will be found to remain in its position.

Pour water very gently into the inside of the glass, and notice the height inside and out at that moment when sufficient water has been introduced to make the disc drop.

The pressure a liquid exerts depends upon the depth below the surface.—Since water and other liquids are material substances, they are pulled downwards by the attractive force of the earth. The amount of this pull measures their weight. The greater the distance below the surface the longer is the column of liquid above any area under consideration; and, as a natural consequence, the greater is the weight of the column of liquid above the given area.

The weight of the column of liquid above unit area, say a square inch, at any depth, measures the *pressure of the liquid* at that depth, and this pressure increases from the surface of the liquid downwards, and is, indeed, directly proportional to the depth. Moreover, as the pressure is measured by the weight of the column of liquid above unit area, it is clear that the denser the liquid the greater is the weight of a column of it, and the greater the pressure it exerts.

And the pressure per unit area exerted by a liquid depends *only* upon the depth. The direction is immaterial, a fact which is clearly brought out by Experiment 24. ii. (*d*), where it is seen that whatever the direction in which the open ends of the bent tubes containing mercury point, the difference in height of the level of the mercury in the two limbs is the same when the depth of the open ends of the tubes beneath the water is the same.

Relation between the pressure of a liquid and the area upon which it acts.—It has been seen that the pressure upon a given area at any depth below the surface of a liquid is measured by the weight of the column of liquid above it. So long as the depth remains the same the pressure upon unit area, a square inch for instance, remains the same. But the larger the number of square inches upon which the pressure of liquid is felt, the greater the *total pressure* upon the area. These facts may be expressed by saying that the total pressure varies in proportion to the areas of the surfaces below any given depth;

or, though the *pressure* (which means per unit area) at any given depth is constant, the *total pressure* is dependent upon area.

These considerations, too, provide an explanation of Experiment 24. iv., where vessels of different shapes and volumes are attached, one by one, to a bent tube with mercury in its bend (Fig. 63). In the circumstances of the experiment, the difference in level of the mercury in the two limbs of the tube containing it remains the same, and consequently the pressure exerted by the water is the same whichever of the variously shaped vessels is attached, provided that the vertical height of the liquid in the tubes is the same. It is necessary to remember that the height and cross-area of the column of liquid, and the density of the liquid are the only things which alter the pressure. And none of these factors vary, however much the shape of the vessel alters. Whatever the shape of the vessel, it acts just as if it were of the simple cylindrical form shown in the middle of Fig. 63. When the wide vessel is attached to the bent tube provided with mercury, the effective pressure at the base is due to the water contained by a cylinder of cross-sectional area equal to that of the upper surface of the mercury, and a vertical height equal to that of the water in the vessel above the mercury.

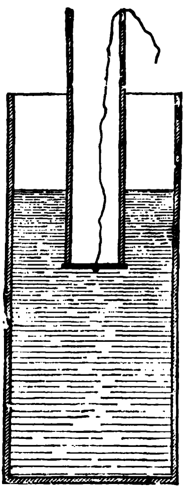

FIG. 64. — Upward pressure of a liquid.

Upward pressure in a liquid.—It has been seen how the pressure at any point in a liquid is estimated, and how the amount of such pressure is determined. It has also been proved by experiment that the pressure is the same in different directions. It would, consequently, be surmised that the pressure acting vertically upwards at a point in a liquid is equal to the downward pressure of the liquid above the point. That this is actually true is easily demonstrated by the simple apparatus shown in Fig. 64. A wide glass cylinder, one end of which is covered with a disc of leather to which a string is attached, as shown in the illustration, is lowered into a liquid. It is found that water may be poured into the cylinder, without disturbing the disc, until the level of the water inside the cylinder becomes

the same as that outside; but, if more water be added, the downward pressure on the upper surface of the disc now exceeds the upward pressure of the outside liquid on the lower surface of the disc, and it is forced downward. So long as the level of the water inside the cylinder is below that of the water outside, the upward pressure on the disc from outside exceeds the downward pressure from inside, and the disc is held firmly against the end of the cylinder. When the water level is the same inside and outside the cylinder, the disc is acted upon by exactly equal upward and downward pressures.

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25. THE PRESSURE OF THE ATMOSPHERE.

i. **Atmospheric pressure.**—(*a*) Select a funnel of the form shown in Fig. 65. Tie a piece of thin sheet india-rubber, such as that used in toy air-balls, over the top. While the rubber remains flat the pressure is evidently the same on both sides of it. Blow into the funnel. Explain why the india-rubber is forced out. Suck the air out of the funnel. What is pressing upon the outside and forcing the india-rubber into the funnel? Suck the air out of the funnel and place your thumb over the open end so as to prevent air from entering. Turn the funnel in various directions and see whether you can detect any difference in the amount of bulging of the india-rubber. If not, you may conclude that the pressure of the air upon the outside is the same in all directions.

FIG. 65.—*A*, funnel with flat membrane over the top; *B*, funnel with membrane made concave by the pressure of the atmosphere.

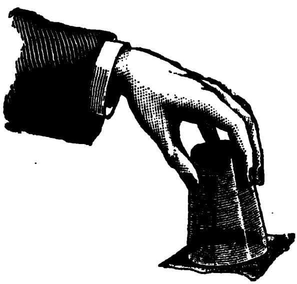

FIG. 66.—The paper remains on the glass on account of atmospheric pressure.

(*b*) Fill a gas collecting jar, or a tumbler having a flat rim, with water; cover it with stout paper and invert (Fig. 66). Why does not the water drop out?

(*c*) Place in water one tube of the Hare's apparatus for determining density (p. 20), and the other tube in mercury. Suck out the air. The liquids rise. Why? Notice the difference in the level of the mercury and the water. Explain the cause of this difference. Let one of the tubes of the Hare's apparatus be much wider than the other. Place the ends of the tubes in mercury, and suck out the air. Is there any difference in the height of the mercury in the large and small tubes?

The pressure exerted by the atmosphere.—The gaseous envelope which surrounds the earth is a fluid, and the pressure it exerts at different distances from the earth varies considerably. The condition of things is different from what has been found in the case of liquids. Gases, as has been seen, are easily compressible. The consequence is, in the case of the air, that the pressure is greatest near the earth or at the bottom of the gaseous ocean round the globe—for so we may regard the atmosphere. But the pressure does not increase in the same simple way as in the case of water. At a point midway between the surface and the bottom of the water in a tank the pressure is just half of that at the bottom of the tank. But in the case of the air the pressure at a height of 3½ miles is just half that at sea-level, though the atmosphere extends for as much as 150 or 200 miles from the earth's surface. Owing to the compressibility of air the lower layers are much denser than those at a height; they are consequently heavier, bulk for bulk, and are able, per unit volume, to exert a greater pressure.

Just as in the case of water, however, the deeper we go into the gaseous envelope, that is, the nearer the earth we get, the greater is the pressure the air exerts. Or, conversely, the higher we ascend into the atmosphere, or the farther from the earth's surface we travel, the smaller is the pressure of the air, simply because, as we ascend we diminish the column of air above us.

26. MEASUREMENT OF THE PRESSURE OF THE AIR.

i. The principle of the mercurial barometer.—Procure a barometer tube and fit a short piece of india-rubber tubing upon its open end. Tie the free end of the tubing to a glass tube about six inches long, open at both ends. Rest the barometer tube with its closed end downwards and pour mercury into it (being careful to remove all air bubbles) until the liquid reaches the short tube. Then fix the arrangement upright as in Fig. 67. The mercury in the long tube will be seen to fall so as to leave a space of a few inches between it

and the closed end. The distance between the top of the mercury column in the closed tube and the surface of that in the open tube will be found to be about 30 inches.

ii. **The cistern barometer.**—Procure a thick glass tube about 36 inches long and closed at one end. Fill the tube with mercury; place your thumb over the open end; invert the tube; place the open end in a cup of mercury and take away your thumb (Fig. 68. Measure the distance from the surface of the mercury in the basin to the top of the mercury column.

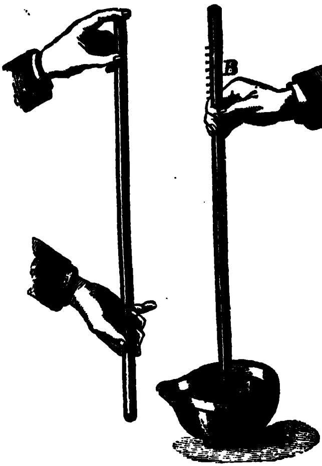

FIG. 68.—Construction of a barometer.

Slant the barometer and measure the vertical height of the mercury by means of a plumb-line. Compare it with the previous reading.

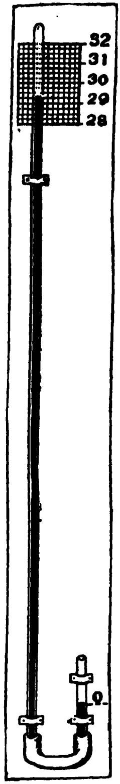

FIG. 67.—A barometer. The pressure of the atmosphere acting upon the open end of the short tube supports a column of mercury about 30 inches long in the closed tube.

The mercurial barometer.—The instrument used in Experiment 26. i. is evidently similar to the U-tube. Referring to Fig. 67 it is clear that there is a column of mercury supported by some means which is not at first apparent, or else the mercury would sink to the same level in the long and the short tubes, for we know that liquids find their own level. If a hole were made in the

closed end of the tube this would immediately happen. There will be no difficulty, from what has been already said, in understanding that the column of mercury is kept in its position by the weight of the atmosphere pressing upon the surface of the mercury in the short open tube. The weight of the column of mercury and the weight of a column of the atmosphere with the same sectional area is exactly the same; both being measured from the level of the mercury in the short stem of the apparatus shown in Fig. 67, the mercury column to the top of the column in the long tube, the air to its upper limit, which, as has been seen, is a great distance from the surface of the earth. If for any reason the weight of the atmosphere becomes greater, the mercury will be pushed higher to preserve the balance; if it should become less, then similarly the amount of mercury which can be supported will be less, and so the height of the column of mercury is diminished.

The height must in every case be measured above the level of the mercury in the tube or cistern open to the atmosphere. In the arrangement shown in the accompanying illustration, a line is drawn at a fixed point *O*, and the short tube is shifted up or down until the top of the mercury in it is on a level with the line.

The student will now understand why it is so necessary to remove all the air bubbles in the last experiments. If this is not done, when the tube is inverted the enclosed air would rise through the mercury and take up a position in the top of the longer tube, above the mercury. The reading would not then be thirty inches, for instead of measuring the whole pressure of the atmosphere, what we should really be measuring would be the difference between the pressure of the whole atmosphere and that of the air enclosed in the tube. In a properly constructed barometer, therefore, there is nothing above the mercury in the tube except a little mercury vapour.

An arrangement like that described constitutes a barometer, which we can define as an instrument for measuring the pressure exerted by the atmosphere.

The cistern barometer.—Other forms of barometer are often employed for the determination of the pressure of air. A very common arrangement is that of Experiment 26. ii., which is a repetition of one by an Italian physicist, Torricelli. The principle of its action is precisely that of the barometer just described, except that the U-tube principle is not immediately apparent.

There is, however, the same balance maintained between the column of mercury in the tube and a column of air outside it, pressing down upon the mercury in the basin.

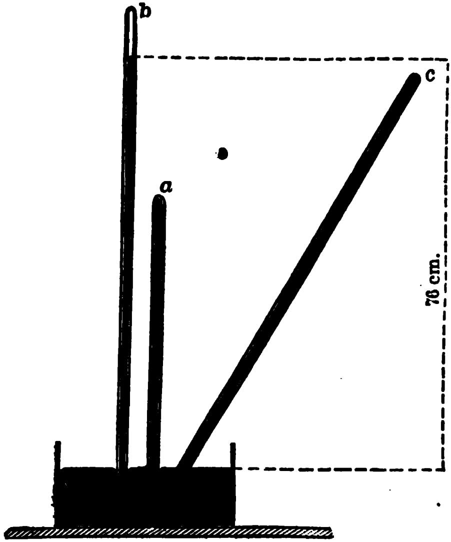

FIG. 69.—The atmosphere at sea level will support a column of mercury up to 30 inches, or 76 cm. in length.

A column of mercury will be supported in the tube by the pressure of the atmosphere. The distance between the top of the column and the surface of the mercury in the cup will be about 30 inches, or 76 cm., when the tube is vertical (Fig. 69, *b*). If the tube is inclined so that the closed end of it is less than this height above the mercury in the cup (Fig. 69, *c*) the mercury fills it completely ; and if the tube is less than 30 inches long, it is always filled by the mercury whether it is inclined or not (Fig. 69, *a*). On an average the atmosphere at sea-level will balance a column of mercury 30 inches in length. No matter if the closed tube is 30 feet long, the top of the mercury column will only be about 30 inches above the level of the mercury in the basin.

The empty space above the column of mercury in the tube is often referred to as the *Torricellian vacuum*.

27. BOYLE'S LAW.

i. Relation between pressure and volume of gases.—(*a*) Select a glass tube about 20 cm. long, and neatly closed at one end (Fig. 70, *A*). Tie a piece of stout india-rubber tubing about a metre long upon the open end of the tube, and fix the other end of the tubing upon a glass tube, *B*, about 20 cm. long, open at both ends. Now carefully fill the tubes with mercury until the level of the liquid is about 10 cm. from the open end. Afterwards fix the closed tube upright in a retort stand with the sealed end upwards, place your finger upon the open end of the other tube, and lower the open end so as to make the air pass into the closed tube. This apparatus will enable you to measure the expansion and compression of air.

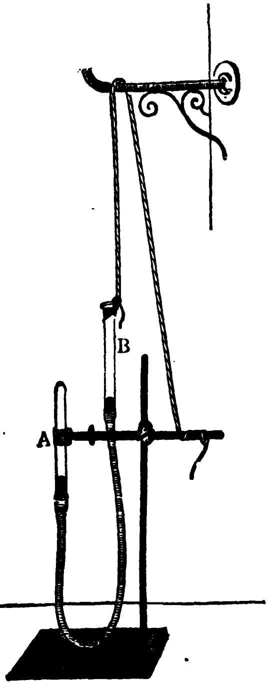

Fig. 70.—To show the relation between the pressure and volume of a gas.

Support the tube *B* with its open end upwards, and at such a height that the mercury stands at the same level in the closed and open tubes. The imprisoned air is then at the same pressure as the air outside.

If the closed tube is uniform in bore, and the inside of the sealed end is nearly flat, the volume of the imprisoned air is proportional to the length of tube occupied by the air, so that if the air is made to occupy one-half the original length of tube its volume is one-half the original volume. The pressure upon the enclosed air is equal to the pressure due to the column of mercury between the level of mercury in the closed tube and that in the open tube, *plus* the pressure of the atmosphere. Observe the height of the barometer, and make the difference of level of the mercury in the two tubes equal to it by lifting the open tube. Then record as follows:

Height of the barometer, - - - -	...... cms.
Length of air column when the mercury is at the same level in both tubes, that is, when the imprisoned air is at atmospheric pressure, - -	...... cms.
Height of barometer ...... cm.+ equal height in tube, - - - - - - - - -	...... cms.
Length of air column under pressure of two atmospheres, - - - - - - - -	...... cms.

The pressure to which the enclosed air is subjected in the second case is double that in the first case; find the proportion in which the volume of the air, represented by the length of the air column, has been diminished.

(*b*) Lower the open tube until the air in the closed tube almost reaches the india-rubber junction. Measure the length of the air column, and the difference of level of the mercury in the two tubes. Repeat the experiment by reading the volume of air and the head of mercury at every few centimetres up to the highest point you can raise the open tube. Record your results as indicated below:

Height of Barometer in cms.	Difference of Level of Mercury in cms.	Total Pressure on the Air, *P*.	Volume of Air, *V*.	Volume × Total Pressure. $(P \times V.)$

ii. **A simple form of Boyle's Law apparatus.***—Take a length of thermometer tubing, AB (Fig. 71), about 75 cms. long and 1 mm. bore. Seal it at B and expand the end A somewhat. Clamp AB in a vertical position by the side of a metre scale, and connect a small funnel to A by means of a short piece of rubber-tubing. Pour a little pure, clean mercury into the funnel and induce it to run down the bore of the tube by inserting a thin, clean, steel wire. In this way any desired volume of air can be enclosed.

The length of the column of enclosed air may be taken to represent its *volume* (V). If H = the height of the barometer, and h = the length of the mercury thread (both expressed in the same units), then the total pressure on the enclosed air $= (H + h)$.

Introduce more mercury in the same manner, and in this way alter the values of V and h. The volume of the air under the pressure of the atmosphere alone can be observed by laying the glass tube flat on the table.

Perform several experiments and record your results in the following way:

Volume (V).	Pressure ($H + h$).	Volume × Pressure.

*Described by Mr. H. E. Hadley, B.Sc., in *The School World*, Nov. 1899.

Boyle's Law.—Before a student can clearly understand how and why the density of the atmosphere varies (p. 92), it is necessary to become acquainted with the rule expressing the relation between the volume and pressure of a gas. This can be satisfactorily done by one of the forms of apparatus employed in Experiments 27. i. and 27. ii., which provide a means of subjecting an enclosed quantity of air to varying pressures, by the addition of smaller or larger quantities of mercury. When in the apparatus shown in Fig. 70 the mercury in both tubes stands at the same level, the enclosed air is acted upon by the pressure of the air alone, but as the tube *B* is raised, the mercury in it stands higher than that in *A*, and the air enclosed in *A* is under a total pressure equal to the sum of that due to the atmosphere and that due to a column of mercury equal in length to the difference of levels of the mercury in *A* and *B*. In these circumstances the volume of the air in *A* decreases, and it decreases more and more as the total pressure is increased. When the results of experiments with any satisfactory form of apparatus are tabulated, certain very important relations between the volume of a gas and the pressure to which it is subjected become evident. It is found that the volume regularly diminishes as the pressure is increased, and in the same proportion. The converse is also found to be true, viz., that as the volume of a gas increases the pressure upon it diminishes and exactly in the same proportion.

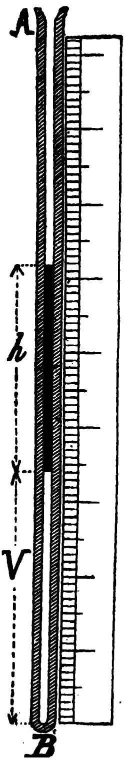

FIG. 71.—Simple form of apparatus for verifying Boyle's Law.

But, in both these cases, it is understood that the temperature of the gas remains the same, that is, the temperature of the gas under the different pressures must not alter.

The tabulated results of the experiments reveal another important relation, which is, however, another way of expressing

those already noticed. It is found that, when there is no alteration of temperature, the product obtained by multiplying the volume of a given mass of gas by the pressure to which it is subjected is always the same, or remains constant.

These facts were discovered by Boyle, and are included in what is known as Boyle's Law. It can be expressed by saying that when *the temperature remains the same, the volume of a given mass of gas varies inversely as its pressure.* Or, what is the same thing, *the temperature remaining the same, the product of the pressure into the volume of a given mass of gas is constant.*

But it has been learnt that if the volume occupied by a given mass of a substance is increased, its density is decreased, and if the volume is decreased, its density is increased. Therefore, by decreasing the volume of the enclosed air in the above experiment, its density is increased. The increase of density and the increase of pressure are proportional to one another. It is not difficult to apply these facts to the case of the atmosphere. It has been learnt that the pressure of the atmosphere decreases as we ascend, and we are now able to add that its density decreases also and at the same rate. Therefore the densest atmosphere is that at the surface of the earth, leaving out, of course, the air of mines and other cavities below the surface, where the air is denser still. The air gets less dense, or rarer, as we leave the earth's surface, until eventually it becomes so rare that its existence is practically not discernible.

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28. SOME INSTRUMENTS DEPENDING UPON FLUID PRESSURE.

i. **The air-pump.**—(*a*) Select a cork or india-rubber stopper which will fit tightly into a brass or glass tube about a centimetre in diameter. Bore a hole through the cork lengthways, and then tie a narrow strip of gold-beater's skin, or oiled silk, over one end of the cork so as to cover the hole. You will find that the silk does not prevent you from blowing through the cork from the open end, but that you cannot suck air through. An arrangement of this kind, which allows passage in one direction but not in the other, is called a *valve.* Wax the cork and fit it tightly in the brass tube (which should be about a foot long) so that the valve is inside. Push a similar valve half way through another brass tube of about the same length, but wider, and wrap darning cotton around the stopped end of the narrow tube until this tube fits nicely into the wider one, and can be moved to and fro like the piston of a popgun. Fit a short U-tube into the cork at one end of the wide tube, as in Fig. 72, and

pour a little mercury into it. The instrument you have constructed is exactly the same in principle as a simple air-pump (Fig. 72).

Moisten the cotton on the piston, either with oil or water. Describe what happens to the enclosed air in the wide tube, and how the valves and the mercury in the U-tube are affected, in each of the following cases: (1) When the piston is pushed inwards; (2) when the piston is pulled outwards. Explain how such an instrument as this enables the enclosed air to be rarefied.

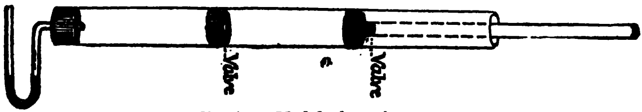

FIG. 72.—Model of an air-pump.

(*b*) Fit a T-piece upon one end of a U-tube containing mercury, as in Fig. 73. Fasten one arm of the T-piece to a water-tap, and turn on the water. Describe the behaviour of the mercury in your U-tube, which is acting as a *manometer*. The principle of this experiment is utilised in the Sprengel air-pump. In this case, however, mercury is the liquid used instead of water.

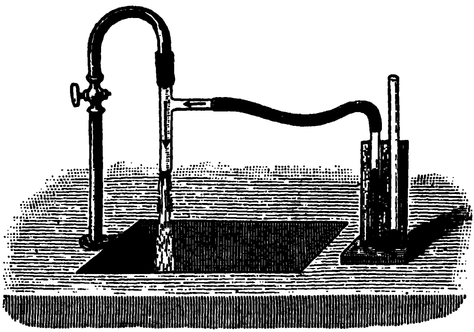

FIG. 73.—Principle of the Sprengel air-pump.

ii. **The common pump.**—Examine a glass working model of a common pump (Fig. 77). Use the pump to lift water, and explain clearly how it acts. Notice that both the valves open outwards or upwards as in the air-pump.

iii. **The siphon.**—(*a*) Make a siphon by bending a glass tube in a fish-tail gas flame; make one limb about 6 inches long and the other at least a foot. Fill the siphon with water, either by placing it in a bucket of water and covering each open end with one of your fingers before lifting it out; or, by sucking water through it as when using your pipette. Allow the siphon to empty itself; from which end does the water flow?

Fill the siphon again, dip the short limb in a beaker of water, and notice what occurs when you take your finger from the long arm. Fill again and let the water flow into a tall narrow vessel. Keep the beaker full of water and notice when the flow of water stops.

(*b*) Connect two short pieces of glass tubing with india-rubber tubing. Fill the tubes with water, and insert the ends below the surface of water in beakers or flasks about half full. Lift one of the

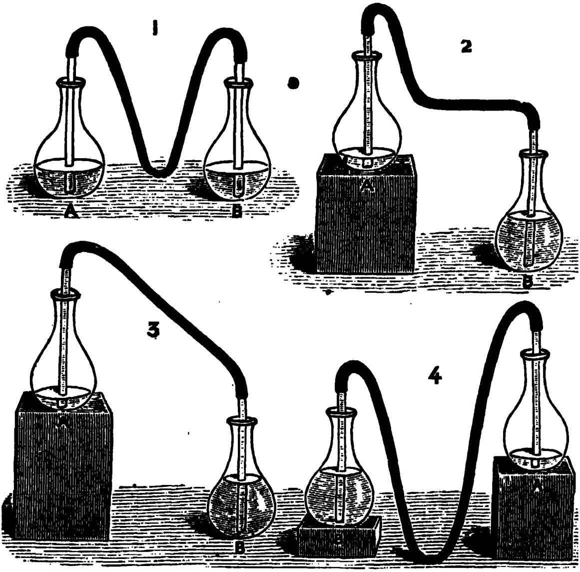

FIG. 74.—In 1 no flow occurs; in 2, 3, and 4 the flow is from *A* to *B*.

flasks, and notice the flow of water which takes place. Show that no flow occurs when the level of liquid is the same in both vessels. Test whether a flow takes place when the bend of the india-rubber is below the lower of the two vessels (Fig. 74).

Observe whether a siphon will act if there is a hole in it.

The air-pump.—Several forms of air-pumps are in use, but in this place it will be sufficient to describe one of the simplest, that designed by Hawksbee, the essential parts of which are shown in Fig. 75. *V* is the receiver, from which it is required to remove air. *V* is connected with a cylinder *Cv* by means of a tube, shown diagrammatically in the illustration, bent twice at right angles. At the end of this tube, remote from the receiver

and just at the bottom of the cylinder *Cv*, is a valve *v* opening upwards. In the cylinder works, in an air-tight manner, a piston provided with a valve *v′* opening upwards; and a handle for pulling the piston up and pushing it down is provided. The action is very simple. Imagine the piston to be at the bottom of the cylinder to begin with, and that it is then gradually pulled up. As this takes place, the air in the receiver and below the valve *v* is subjected to a diminished pressure, and consequently expands, filling the space which is formed as the piston moves upwards. This continues until the piston arrives at the end of its stroke. The piston is now pushed down. This compresses the air between *v′* and *v* and increases its pressure, causing the valve *v* to shut. But as the piston descends the pressure on the under surface of the valve *v′* becomes greater than that of the atmosphere upon its upper surface, with the result that the valve *v′* opens upwards and the air in the space *vv′* rushes through the open valve into the outside air. The final result, when the piston reaches the bottom of the cylinder, being that there is less air in the receiver and tube connecting therewith than there was originally. As the piston is worked up and down the same opening and shutting of valves is repeated, with the result, that by and by, all the air is removed from the receiver.

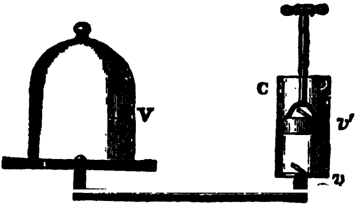

FIG. 75.—Simple form of air-pump.

Sprengel's air-pump.—More perfect vacua can be obtained by a simple form of air-pump, due to Sprengel, in which the piston of Hawksbee's instrument is replaced by drops of mercury and in which valves are dispensed with. The essential parts of this pump are shown in Fig. 76. *C* is the flask, or other vessel, which it is desired to exhaust of air. This vessel is suitably attached to a side tube connecting with a vertical tube *ABD*, provided with a funnel *A* at one end, and a receptacle *D* at the other for catching the mercury as it drops.

Mercury is poured into the funnel and falls continuously down the long vertical tube. As each drop of mercury passes *B*—the opening of the side tube connected with the vessel *C* to be exhausted—it carries with it a little air from *C*, until eventually,

after the stream of mercury has been running for some time, practically the whole of the air in *C* is removed.

The common pump. — After examining a glass model like that shown in Fig. 77, there is no difficulty in understanding the action of a common pump. To begin with, suppose that the pump is full of air and that the end

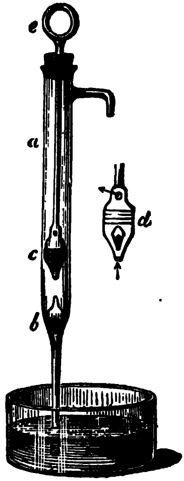

FIG. 77.—Model of a common pump.

of the tube below the valve *b* is dipped into a basin of water. The piston *ec* is, to start with, at the bottom of its stroke near the valve *b*. As the piston is raised the air in the cylinder above *b* expands, and its pressure consequently decreases, the pressure on the lower surface, of the valve *b* is, therefore, soon greater than that on its

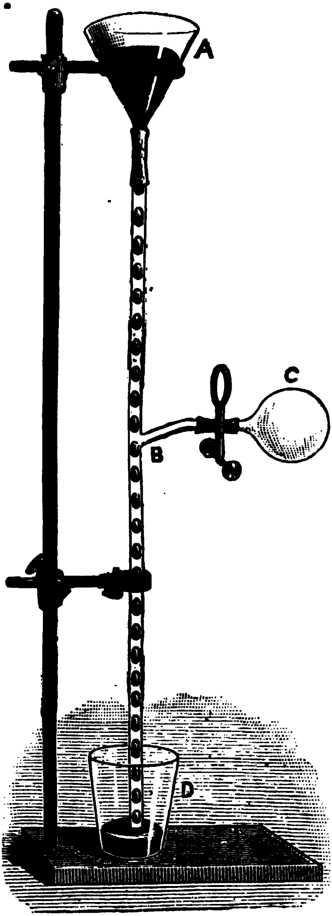

FIG. 76.—Simple form of Sprengel air-pump.

upper surface and it is pushed upwards by the air below it, the air flowing into the cylinder *acb*. The result of this is that the air in the cylinder below the piston is of a lower pressure than that of the outside air, and as a consequence water is pushed up the tube *b*. This action continues until the piston reaches the end of its stroke towards the top of the pump.

As the piston descends, the air in the cylinder below the piston *c* is compressed and its pressure becomes gradually greater. This closes the valve *b* and opens that in *c*, through which latter, of course, the air in the cylinder escapes. On raising the piston again the same effects are repeated until all the air in the pump is removed and the outside air pushes the water up until it reaches the spout and escapes.

It has been learnt that the air is able to support a column of mercury 30 inches in height, and as mercury is about $13\frac{1}{2}$ times heavier than water it is clear that the air could support a column of water of a height equal to

$$30 \text{ inches} \times 13\tfrac{1}{2} = 2\tfrac{1}{2} \times 13\tfrac{1}{2} \text{ ft.} = 33\tfrac{3}{4} \text{ ft.},$$

and it will at once be understood, since the efficacy of the common pump depends wholly upon the pressure of the air, that the spout of the pump must never be more than $33\frac{3}{4}$ feet, or, roughly, 33 feet from the level of the water.

The siphon.—The siphon is a simple instrument which can be easily understood after what has been said about atmospheric pressure. It consists usually of a bent tube, one leg of which is longer than the other. It is filled with the liquid to be transferred from one vessel to another, and while both ends of the tube are kept closed, the shorter limb is placed into the vessel of liquid. The result is that the liquid flows until the level of the liquids is the same in both vessels, or the higher liquid has been siphoned to the lower level.

Suppose a siphon having limbs of equal length to be placed with the ends in two jars containing mercury at the same level, as in Fig. 78, *A*. For simplicity, suppose each tube to have a length of 30 inches, and let the surface of the mercury in each vessel be 12 inches from the bends of the tube. Under normal conditions the atmosphere is able to support 30 inches of mercury, but in the case illustrated the height of the mercury columns is only 12 inches. There is thus a surplus atmospheric pressure equal to 18 inches of mercury acting on the surface of the

mercury in the jars; but as it is the same in each, the mercury in the bent tube does not move.

But now consider the conditions represented in Fig. 78, *B*. The 30 inches of mercury in the left-hand tube just balances the atmospheric pressure on the surface of the mercury into which it dips. On the right-hand side, however, the mercury column is only 12 inches high, so there is a surplus atmospheric pressure equal to 18 inches of mercury. The mercury is there-

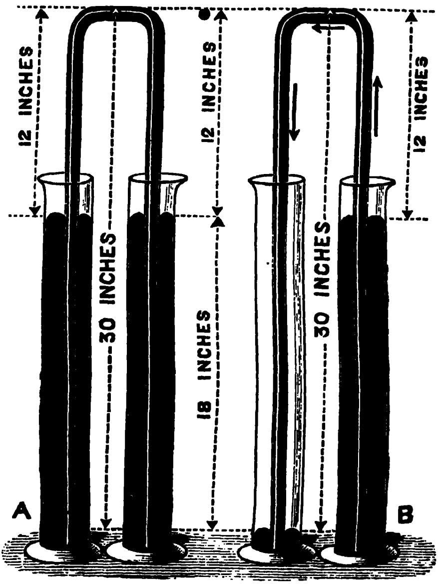

FIG. 78.—To explain how the action of a siphon depends upon atmospheric pressure.

fore forced through the tube, and the flow goes on until the level is the same in each vessel. It is thus seen that *the force tending to push the liquid up an arm of a siphon is equal to the atmospheric pressure minus the pressure due to the liquid in that arm.*

Since the instrument depends upon the pressure of the atmosphere for its efficiency, it is clear that if the bend of the siphon is at a greater height above the level of the liquid

than that which can be supported by the pressure of the atmosphere, then the siphon will not act.

When the liquid is water, the height of the bend above the higher liquid surface must not exceed 33 feet (p. 104), and when mercury is being transferred by a siphon, this height must be under 30 inches.

CHIEF POINTS OF CHAPTER VII.

Pressure on liquids.—Liquids communicate pressure equally in all directions. The pressure *per unit area* which a liquid exerts depends only upon the depth below the surface—the direction is immaterial. The *total* pressure at any place within a liquid varies with the area considered. The pressure acting vertically upwards at a point in a liquid is equal to the downward pressure of the liquid above the point.

The pressure of the atmosphere is due to its weight. The pressure diminishes as an ascent from the earth is made. At a height of 3½ miles the pressure is only one-half that at sea-level.

The barometer is an instrument for measuring the pressure exerted by the atmosphere. The pressure of the atmosphere balances a column of mercury about 30 inches in length.

Boyle's Law states the relation between the volume and pressure of a gas. It can be expressed by saying that, the temperature remaining the same, the volume of a given mass of gas varies inversely as its pressure. Or, what is the same thing, the product of the pressure into the volume of a given mass of gas is constant.

The air-pump is an instrument for removing the air from a closed reservoir.

The **common pump** and the **siphon** depend for their action upon the pressure exerted by the atmosphere.

EXERCISES ON CHAPTER VII.

1. Some deep-sea animals, when brought to the surface, become very much larger. Why is this?

2. Describe a simple experiment to show that the pressure in a liquid increases with the depth below the surface. What pressure, expressed in grams' weight, would be exerted upon a square of glass of a decimetre side immersed to a depth of 10 metres in the water of a lake?

3. How would you prove to a class that the upward pressure per unit area at a depth of 10 feet below the surface of the sea is equal to a column of water 10 feet high and unit area in cross section?

4. Given a glass tube, thirty-two inches long, closed at one end, a bottle of mercury (quicksilver), and a small cup. State how you proceed (*a*) to construct a barometer, and (*b*) to show the readings of this barometer. (1896.)

5. (*a*) State the average height of the mercury in a barometer at the sea-level, and at the top of a mountain three and a half miles high.

(*b*) What is the cause of the difference in the height of the mercury column?

(*c*) What do you know concerning the height to which the atmosphere extends?

(*d*) What do you know concerning the condition of the upper layers of the atmosphere? (1895.)

6. State the principle on which the action of a mercurial barometer depends. Why is a water barometer longer than a mercurial barometer? What occupies the space above the mercurial column in the latter instrument? If a hole were to be bored through the glass above the column of mercury, what would happen? (1891.)

7. How can the weight of the air be determined? In what way is the pressure exercised by the atmosphere on the earth's surface, in consequence of its weight, stated? How is it that we are able to move about under the weight of the atmosphere? (1889.)

8. Enunciate the law associated with the name of Boyle. Describe a simple form of apparatus to prove that, if a given mass of air is acted upon by a pressure twice as great as that of the atmosphere, its volume becomes one half what it was originally.

9. Draw a common pump, and explain how it acts. At what depth will such a pump become ineffective?

10. What is a siphon? What experiments would you perform to explain its action to a class?

11. Make a sketch of some form of air pump. Describe clearly how it is that valves are dispensed with in Sprengel's pump.

12. About what height does the mercury column of the barometer generally stand? Explain why the tube must be kept in a vertical position. (Queen's Sch., 1899.)

CHAPTER VIII.

EFFECTS OF HEAT. THERMOMETERS.

29. CHANGE OF SIZE.

i. **Expansion of solids.**—(*a*) Procure an iron or brass rod *AB*, about six inches long which fits into a "gauge" cut out of a sheet of thin brass, as shown in Fig. 79. Observe that the metal rod just fits the gauge. Heat the rod by a spirit lamp or laboratory burner. The rod is now too large to go into the gauge.

(*b*)* Using four knitting needles, three corks, a sewing needle, and a glass of water, fit up the arrangement shown in Fig. 80. The horizontal needles are only to steady the arrangement. Let the point of the sewing needle project just above the surface of the water. Heat with a lighted match the needle hanging inside the glass. The steel expands, and the point of the sewing needle will be seen to disappear below the

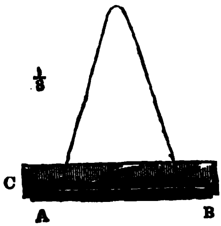

Fig. 79.—Rod and gauge for showing expansion produced by heat.

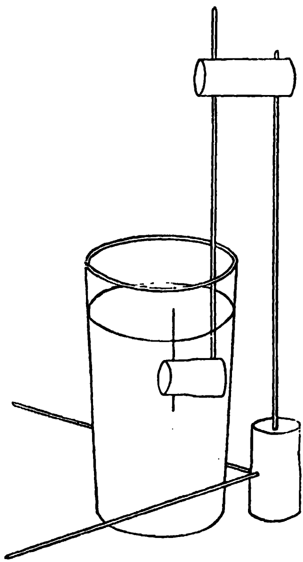

Fig. 80.—Simple method of showing expansion produced by heat.

* This experiment is due to Mr. Horace Darwin.

surface of the water. Heat the knitting needle outside, and the expansion produced will bring up the point of the sewing needle again. These small movements can be easily seen by watching the reflection of a bright object in the surface of the water.

(*c*) Solder a strip or wire of brass, about two feet long, to one of iron of the same length. Straighten the compound strip by hammering; then heat it. Notice that the strip bends, because the brass expands more than the iron. The same effect can be shown by means of a strip of ebonite glued to a strip of wood, on account of the ebonite expanding more than the wood (Fig. 81).

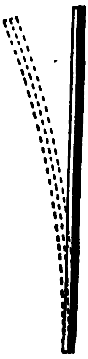

FIG. 81. — Compound strip of ebonite and wood to show greater expansion of ebonite when heated.

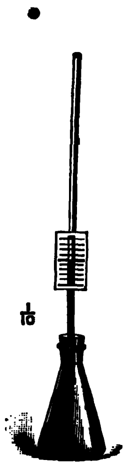

FIG. 82.—Flask fitted with tube to show expansion of liquid produced by heat.

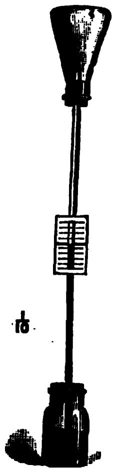

FIG. 83.—An air thermometer.

ii. **Expansion of liquids.**—(*a*) Procure a 4-oz. flask and fit it with a cork. Bore a hole through the cork and pass through it a long glass tube which fits tightly. *Fill* the flask with water coloured with red ink. Push the cork into the neck of the flask and so cause the coloured water to rise up the tube. See that there is no air between the cork and the water. Now dip the flask in warm water, and notice that the liquid soon gets larger and rises up the tube (Fig. 82). Take the flask out of the warm water, and see that the coloured water gets smaller as it cools, and that it sinks in the tube.

(*b*) Arrange two other flasks as in the last experiment, but filled respectively with alcohol and turpentine. Push in the corks till the liquid stands in each tube at the same height. Put all three flasks to the same depth into a vessel of warm water. Notice that

the expansion of the glass causes a momentary sinking of the liquids; and that ultimately the expansions of the three liquids are very different.

iii. **Expansion of gases.**—(*a*) Procure a well-made paper bag and tightly tie a piece of tape round the open end. Hold the bag in front of the fire, and notice that the air inside gets larger and inflates the bag.

(*b*) Or, obtain a flask with a cork and tube, as in Fig. 83. Remove the cork and tube, and, by suction, draw a little red ink into the end of the tube near the cork. Re-insert the cork, and gently warm the flask by clasping it in your hands. Notice that the air in the flask gets larger and pushes the red ink along the tube.

(*c*) Turn over and place the open end of the tube beneath the surface of some coloured water in a beaker. Warm the flask with the hand or a flame so as to expel some of the air, and let the liquid rise in the stem (Fig. 83). (This constitutes an *air thermometer*.)

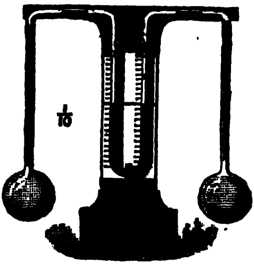

FIG. 84.—A differential thermometer.

(*d*) Fit a 2-oz. flask with a tight cork through which a tube passes, the upper end of which is bent down and then up at the end. Clamp the flask so that the end of the tube dips under water in a basin. Fill a test-tube with water, and invert it over the end of the tube. Warm the air in the flask, and collect the expelled air in the test-tube.

(*e*) Fasten two bulbs or flasks together (air-tight) by a tube bent six times at right angles, and containing some coloured liquid in the middle bends (Fig. 84). Show that the liquid moves if one flask is warmed more than the other. (This instrument is known as a *differential thermometer*.)

Change of size. Expansion.—As a rule all bodies, whether solid, liquid, or gaseous, get larger when heated, and smaller when cooled.

The change of size which a body undergoes is spoken of as the amount it expands or contracts; or, heat is said to cause expansion in the body. This expansion is regarded in three ways. When dealing with solids, expansion may take place in length (linear expansion), in area (superficial expansion), and in volume (cubical expansion). In the case of liquids and gases we have only cubical expansion. Similar terms can be used with reference to contraction.

The expansion which substances undergo when heated has to be allowed for in many things. Railway lines, for instance, are

usually not placed close together, but a little space is allowed between the separate rails, so that they can expand in summer without meeting. Steam pipes used for heating rooms are also not firmly fixed to the walls at both ends, but are left slightly loose or are loose-jointed, so that they can expand or contract without doing any damage. For the same reason the ends of iron bridges are not fixed to the supports upon which they rest. Iron tyres are put on carriage wheels by first heating the tyre and, while it is hot, slipping it over the wheel. As the tyre cools it contracts and clasps the wheel very tightly.

The common occurrence in domestic life of the cracking of thick glasses when boiling water is poured on them, is to be explained by this expansion of solids by heating. The part of the glass with which the hot water comes in contact is heated and expands; but the effect is quite local; the heating is confined to one spot, because glass does not allow heat to pass through it readily. It is this local expansion of the glass which results in the cracking of the vessel.

Measurement of change of temperature.—Change of temperature means change in the state of hotness or coldness of a body. The change of size which takes place when a thing is heated gives a good way of measuring the change of temperature which it undergoes. Think of the experiment with the coloured water in the flask with a long tube attached to it. Suppose the coloured water in the tube rises through a certain number of inches after the water has been heated somewhat, and that when the flask is placed into some other liquid, or some more water, the coloured water is found to rise up the tube to just the same place, we should have every right to say that the second liquid is exactly as hot as the first was. This is measuring its temperature. The flask and tube with the water have become a "temperature measurer," that is, a *thermometer*.

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30. TEMPERATURE AND THERMOMETERS.

i. **The sense of feeling may be deceived.**—Arrange three basins in a row; into the first put water as hot as the hand can bear, into the second put lukewarm water, and fill the third with cold water. Place the right hand into the cold water and the left into the hot, and after half a minute quickly put both into the lukewarm water. The left hand feels cold and the right hand warm while in the same water.

ii. **Measuring temperature.**—(*a*) Place the flask of water, with fitted tube used in Experiment 29. ii. *a*, in hot water, and notice the height of the liquid in the tube. Transfer it to cold water, and observe that the liquid in the tube sinks.

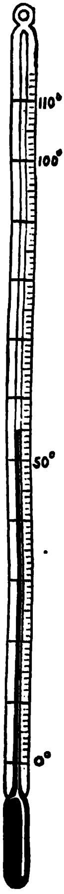

FIG. 86.—A thermometer of the form used for scientific work.

(*b*) Procure an empty thermometer tube, with a bulb at one end. (If a blowpipe is available, a bulb can easily be blown upon one end of the tube by melting the glass in the flame, and blowing down the open end while the other end is molten.) Heat the bulb (Fig. 85), and while it is hot dip the open end in mercury. As the bulb cools, mercury will rise in the tube to take the place of the air driven out by the expansion of the air in the tube by heat. Repeat the operation until the mercury fills the bulb and part of the stem.

FIG. 85.—Stage in the construction of a thermometer.

(*c*) Place in hot water the bulb of the instrument just constructed, and make a mark at the level of the mercury in the tube. Now place the instrument in cold water, and notice that the mercury sinks in the tube. The mercury is thus seen to expand when heated and contract when cooled, and if the glass were marked, the degree of hotness or coldness could be shown by the position of the top of the mercury.

(*d*) Examine a thermometer. Notice that it is similar to the simple instrument already described, but the top is sealed up, and divisions or graduations are marked upon it, so that the height of the mercury in the tube can be easily seen. These divisions are called *degrees* (Fig. 86).

Feeling of heat and cold.—Some people feel cold at the same time that others feel warm. You can therefore easily understand that the sense of feeling cannot be depended upon to tell us accurately whether the air or any substance is hot or cold. Some instrument is needed which does not depend upon feeling, and cannot be deceived in the way that our senses can. Such an instrument is called a *thermometer*, and it is used to measure temperature, that is, the degree of hotness or coldness of a body.

How expansion may indicate temperature.—You have already learned that substances usually expand when heated and contract when cooled. A flask filled with water, for instance, and having a stopper through which a glass tube passes, can be used to show the expansion produced by heat and the contraction by cold. But this flask and tube make but a very rough temperature measurer. The water does not get larger to the same amount for every equal addition of heat. Neither is it very sensitive, that is to say, it does not show very small increases in the degree of hotness or coldness, or, as you should now learn to say, it does not record very small differences of temperature, and for a thermometer to be any good it must do this. Then, too, as every one knows, if water is made very cold it becomes ice, which, being larger than the water from which it is made, would crack the tube. For many reasons, therefore, water is not a good thing to use in a thermometer.

Choice of things to be used in a thermometer.

1. *The substance used should expand a great deal for a small increase of temperature.*

Gases expand most, and solids least, for a given increase of temperature. Liquids occupy a middle place. The most delicate thermometers are therefore those where a gas, such as air, is the substance which expands. But in common thermometers a liquid, either quicksilver or spirits of wine, is used. Both these liquids expand a fair amount for a given increase of temperature, and, to make this amount of expansion as great as possible, they are used in fine threads by making them expand in a tube with a very fine bore.

2. *If a liquid is used it should not change into a solid unless cooled very much, nor into a gas unless heated very much.*

We cannot be sure of both these things in the same thermometer. When a thermometer is required for measuring very low temperatures it usually contains spirits of wine,

because this liquid has to be cooled a very great deal before it is solidified, that is, made into a solid. But we cannot use this thermometer for any great degree of temperature because it is soon completely changed into a vapour when heated to only a comparatively small extent. If we wish to measure higher temperatures we use a quicksilver or mercury thermometer, because mercury can be warmed a good deal, or, as it is better to say, raised to a high temperature, without being changed into a gas.

FIG. 87.—Thermometer in course of construction. *A* contains liquid to fill the thermometer, and *B* shows the place where the stem is melted and sealed.

3. *The liquid should be in a fine tube of equal bore with a comparatively large bulb at the end.*

We have seen that liquids have to be contained in some sort of vessel or else we cannot keep them together. We know, too, that we must have a fine bore, so that the liquid may appear to expand very much for a small change of temperature. The bore must be equal all the way along, that is, the width or diameter of the inside of the tube must be the same all the way along, so that a given amount of expansion in any part of the tube shall mean the same change of temperature; and, lastly, there must be a large bulb, so that there is a large surface to take the same temperature as that of the substance the temperature of which we wish to measure.

Reasons why mercury is used for thermometers.—There are many reasons for selecting mercury as the liquid for an ordinary thermometer in addition to those already mentioned. It is a liquid the level of which can be easily seen; it does not wet the vessel in which it is contained; it expands a considerable amount for a small increment of temperature; it is a good conductor of heat, and consequently it very quickly assumes the temperature of the body with which it is placed in contact. Very little heat is required to raise its temperature, and there is therefore very little loss of heat due to warming the thermometer.

Construction of a thermometer.—Having selected a suitable piece of thermometer tubing, a bulb must be first blown on one end. The glass is melted at this end and allowed to run together and so close up the bore, and while the glass is still molten, air is blown down the tube from the other end, keeping the tube moved round, so that the bulb is symmetrically placed with reference to it. The bore of the tube is so fine that it is impossible to pour the liquid down it; some other plan must therefore be adopted. The tube is warmed and inverted in some of the liquid. The top of the tube is usually blown into a funnel shape as shown at *A* in Fig. 87, and liquid with which the thermometer is to be filled is put into it. Let us suppose mercury is being used. Warming the tube makes the air inside it expand, and of course some is driven out. As the tube cools the mercury is forced in, by the weight of the atmosphere, to fill the place of the expelled air. By repeating this alternate process of warming and cooling, in the circumstances we have described, enough mercury is soon introduced into the tube. The next step is to seal up the tube, leaving no air above the mercury; to do this the bulb is heated to a temperature slightly higher than we shall want our thermometer to register. The mercury expands, and when it has reached the drawn-out part, *B*, of the tube, a blow-pipe flame is directed against it, and the tube is thus closed up. This method of closing a tube and keeping the air out is called *hermetically* sealing it. The thermometer at this stage should be put on one side for some days at least, in order that it may assume its final size, which it does very slowly indeed.

31. GRADUATION AND USE OF THERMOMETERS.

i. **The temperature of melting ice.**—(*a*) Take some pieces of clean ice in a beaker or test-tube and plunge a thermometer amongst them. Notice the reading of the thermometer; it will be either *no degrees* (0°) or very near it.* Warm the beaker or test-tube, and observe that as long as there is any ice unmelted the reading of the thermometer remains the same.

(*b*) Repeat the experiment with pieces of some other blocks of ice, and observe the important fact that the temperature of clean melting ice is the same in all your tests.

* A Centigrade thermometer is supposed to be used. If a Fahrenheit thermometer is used the reading will be 32°.

ii. **Effect of adding salt to the ice.**—(*a*) Add salt to the melting ice, and notice that the thermometer indicates a lower degree of temperature.

iii. **The temperature of boiling water.**—(*a*) Boil some distilled water in a flask, test-tube (Fig. 88), or beaker, and plunge a thermometer in the boiling water. Notice the temperature. Raise the thermometer until the bulb is just out of the water and only heated by the steam. Again record the temperature. In both cases the reading is the same. It is either *one hundred degrees* (100°), or very near it, if you use a thermometer with Centigrade divisions.

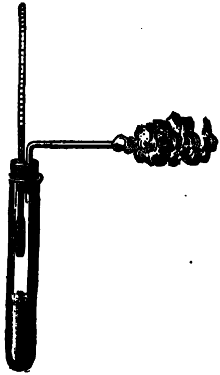

FIG. 88.—Test tube with thermometer fitted for observing the boiling point of water.

(*b*) Repeat the experiment with a second lot of pure water, and note that the temperature of boiling water is again 100°.

(*c*) Add salt to the water. Hold a thermometer in the steam of the boiling water, and notice that the temperature is the same as before, namely, 100°. Push the thermometer into the water, and notice that a higher degree of temperature is indicated.

(*d*) Again place the thermometer in clean ice in a test-tube or flask. Gently heat the vessel, and notice the following changes:

(1) The mercury remains at 0° until all the ice is melted.

(2) When the ice is melted the mercury rises gradually until it reaches 100°.

(3) The mercury remains stationary at 100° until all the water is boiled away.

iv. **A thermometer cannot be deceived.**—Arrange three basins of cold, lukewarm, and hot water side by side. Place the thermometer in the cold water and then in the lukewarm water. Notice the temperature indicated in the lukewarm water. Now place the thermometer in the hot water, and when it has been there a minute or two put it into the lukewarm water. Notice that the temperature indicated is practically the same as before. It is thus seen that, unlike our sense of feeling, a thermometer is not deceived by being made hot or cold before using it to indicate temperature.

v. **Common temperatures.**—(*a*) Notice the temperature of the room indicated by the thermometer.

(*b*) Place the thermometer in your mouth, and notice the temperature indicated by it at the moment it is removed.

The fixed points on a thermometer.—In the graduation of a thermometer the plan always adopted is to choose "two fixed points" from which to number our degrees of temperature. The most convenient lower fixed point we can get is the temperature at which ice melts, or water freezes, for this is

always the same if the ice is pure, and remains the same as long as there is any ice left unmelted. Whenever the thermometer is put into melting ice the mercury in it always stands at the same level, or melting ice is always at the same temperature and thus may be used to give one fixed point. The "higher fixed point" chosen is that at which pure water boils at the sea-level. We have to make this stipulation, for the boiling point of a liquid is altered when the pressure upon it is changed, being raised if the pressure is greater, and lowered if the pressure is less. When the water boils the temperature of the steam is the same as that of the water, and remains so as long as there is any water left. The lower fixed temperature we refer to as the "Freezing Point of Water," the higher as its "Boiling Point."

Marking the freezing point.—For this purpose an arrangement like that shown in Fig. 89 is very suitable. The funnel is filled with pounded ice, which before powdering had been carefully washed; or snow might, if more convenient, be used. The glass dish catches the water which is formed from the melting of the ice or snow. A hole is made in the pounded ice by thrusting in a pencil or glass tube about the size of the thermometer, and into this hole the thermometer is put and is so supported that the whole of the mercury is surrounded by the ice or snow. The arrangement is left for about ten or fifteen minutes, until it is quite certain that the tube and mercury are at the same temperature as the melting ice. When this is so the tube is raised until the mercury is just above the ice, and a fine scratch made with a three-cornered file on the tube at the level of the mercury.

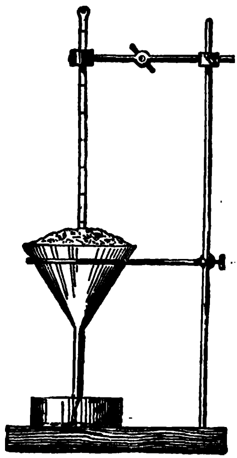

FIG. 89.—Thermometer in ice for the observation of freezing point.

Marking the boiling point.—On account of the condensation of vapour upon the thermometer, the method used in Expt. 31. iii. *a* to find the boiling point is not a very accurate

one. More exact determinations can be made by means of the apparatus shown in Fig. 90. A can or flask *F* is fitted with a cork, through which a glass or brass tube *B* passes. Surrounding this tube is a wider tube *C*, fitted upon the inner tube by means of a piece of thick india-rubber tubing *D*. At the top of the outer tube is a cork *E* having a hole in which a thermometer can be fitted. When the water in the flask is boiled, steam passes up the inner tube *B*, and down the wide tube *C*, and escapes at the outlet *G* into the open air. To use the apparatus, the top of the stem of the thermometer is gently pushed into the cork which fits in the outer tube, and adjusted so that the 100° point is just below the cork. The cork is then fitted into its place, the water boiled, and when steam has been coming off for about a quarter of an hour, the thermometer is read. The observation is repeated after a few minutes, and when two readings obtained at an interval of about ten minutes agree, the point at which the top of the liquid stands is marked upon the stem. The temperature observed is the boiling point of water under the particular conditions existing at the time and place of the experiment.

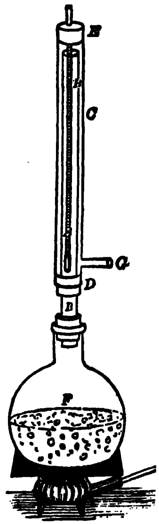

FIG. 90.—Flask fitted for the determination of boiling point.

Precautions necessary in marking the fixed points.—Since experiments have shown that the mixture of common salt with ice or snow lowers the temperature of the ice or snow, great care must be taken that pure clean ice is used when the lower fixed point of a thermometer is being marked. It must also be noted that the presence of substances other than common salt similarly have an effect on the temperature.

It has also been seen that the temperature of a boiling solution of common salt in water is higher than that of the steam which is given off from it. Moreover, since it is the temperature of the steam from boiling water which alone remains constant at the sea-level (the nature of the containing vessel and the presence of substances in solution affecting the temperature of the liquid), in marking the higher fixed point of

a thermometer the instrument should be surrounded by the steam and not placed in the liquid. It will be seen more fully later that an increase of atmospheric pressure, represented by an increased barometric height, raises the temperature at which water boils, hence the height of the barometer must be recorded when the higher fixed point is being marked.

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32. EFFECT OF PRESSURE ON THE BOILING POINT.

i. **Water boiling under diminished pressure.**—Boil some water in a flask, and let it continue to boil for some minutes until you can be sure all the air is driven out of the flask. Remove the burner and quickly insert a well-fitting cork. Allow the flask to remain to cool for a few minutes, then turn it upside down on a suitable support and throw cold water on to the flask. Notice the water again starts boiling vigorously.

Water boils at a lower temperature under diminished pressure.—Though it has been stated in general terms that the temperature at which water boils is quite definite, this is only true when the pressure of the air is the same. Pressure has a great influence on the boiling point of a liquid. The weight of the atmosphere is very considerable, being at the surface of the earth equal to that of a mass of 15 lbs. on every square inch. In studying the pressure of the atmosphere it was seen that its amount upon an object depends upon the extent of the air above the object. This will evidently be less at the top of a mountain than at the bottom of a mine, and consequently the pressure of the air will be in the former situation less than in the latter. If we wish to boil a liquid, therefore, in those cases where the pressure of the atmosphere is great, we shall have to heat the liquid more before the bubbles of vapour formed can escape at the surface

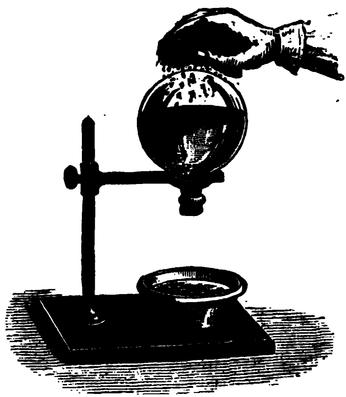

FIG. 91.—Experiment to show that water can be made to boil at a lower temperature than 100° C. when the pressure is diminished.

than when the pressure is less. If we heat the liquid more its temperature will get higher before there is any conversion into vapour, and consequently its boiling point will be higher when the pressure is greater. In finding the boiling point of a liquid we must therefore know the pressure of the atmosphere at that time and place.

A very simple experiment proves that water may boil at a temperature considerably below 100° C. when the pressure upon its surface is diminished. Water is boiled in a flask fitted with a good cork or india-rubber stopper; the boiling is allowed to continue for some minutes, so that all the air in the flask is driven out and its place taken by steam. The burner is then removed and the cork inserted into the neck of the flask as rapidly as possible. After standing to cool for a minute or two, when its temperature can no longer be 100° C., the flask is turned over and cold water poured upon its upturned under surface, or a cold wet sponge is squeezed upon it as shown in Fig. 91. The cold water causes the steam in the flask to condense, and as no air can get in, the pressure on the surface of the warm water is now less than it was before, and the water is seen to boil quite briskly again, though the temperature is below the ordinary boiling point of water.

Thermometer scales.—Some value must now be given to the two fixed points which have been obtained as previously described, and of course they could be called anything the maker of the thermometer liked, but for the sake of comparing one man's observations and experiments with those of other people, it is most convenient to graduate all thermometers in the same way. The thermometers used in this country are divided up in two ways—(1) the Centigrade scale, (2) the Fahrenheit scale. A third scale—the Réaumur scale is extensively used in Germany.

The Centigrade scale.—Here the freezing point is called *zero* or *no degrees Centigrade*, written 0° C. The boiling point is called *one hundred degrees Centigrade*, and is written 100° C. The space between these two limits is divided into 100 parts, and each division called a *degree Centigrade*.

The Fahrenheit scale.—On thermometers marked in this way the freezing point is called *thirty-two degrees Fahrenheit*, written 32° F., and the boiling point *two hundred and twelve degrees Fahrenheit*, written 212° F. The space between the

two limits is divided into 180 parts, and each division is called a *degree Fahrenheit.* The reason of this difference is interesting. The physicist Fahrenheit, after whom the thermometer is named, got, as he thought, a very low temperature, by mixing common salt with the pounded ice when measuring the lower fixed point, and he wrongly imagined that he had got the lowest temperature which could be reached, and called it

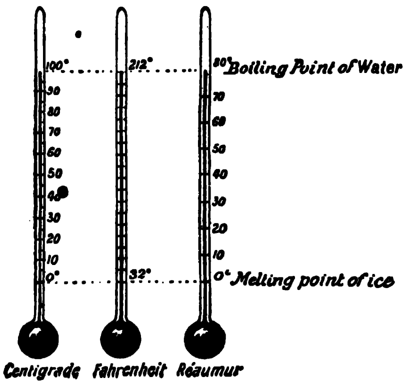

FIG. 92.—Thermometric scales.

The Réaumur scale.—Upon thermometers graduated according to this scale the freezing point is marked 0° and the boiling point 80°. The relation between the three scales is shown in Fig. 92.

Conversion of scales.—It should be clear from what has been said that the interval between the boiling and freezing points, that is, the same temperature difference, is divided into 100 parts on the Centigrade scale and 180 parts on the Fahrenheit, and consequently 100 Centigrade degrees are equal to 180 Fahrenheit degrees, which is the same as saying one degree Centigrade is equal to nine-fifths of a Fahrenheit degree, or one degree Fahrenheit is equal to five-ninths of a degree Centigrade.

100 C. degs. = 180 F. degs. ; $\therefore$ 5 C. = 9 F. $\therefore$ C. = $\frac{5}{9}$ F. or F. = $\frac{9}{5}$ C.

In converting Fahrenheit readings into Centigrade degrees, we must substract 32 (because of what has been said of the freezing point on the former scale) and multiply the number thus obtained by 5 and divide by 9. To change from Centigrade to Fahrenheit, multiply the former reading by 9 and divide by 5 and add 32 to the result.

Example.—What temperature on the Fahrenheit scale corresponds to 20° C.?

Answer.—20° C. is 20 C. degs. above the temperature of melting ice, *i.e.* 20 × $\frac{9}{5}$ Fahr. degs. above 32° F. = (36 + 32)° F. = 68° F.

When it is necessary to refer to temperatures lower than the freezing point of water, a minus sign is placed before the temperature, thus, three degrees below the freezing point of water on the Centigrade scale is written − 3° C.

33. WATER DOES NOT EXPAND REGULARLY WHEN HEATED.

i. **Anomalous expansion of water.**—(*a*) Make a coil of lead composition tubing. Fit an india-rubber stopper, or a good cork, having a glass tube of narrow bore through it into one end of the coil. Suck boiled water into the coil until it can be seen in the glass tube above the stopper, and then fit a good stopper into the other end of the coil. Fasten a scale to the glass tube, and then place the coil with the tube and scale into a bowl of water at the temperature of the room, and hang a thermometer in the water. Notice the position of the surface of the water in the tube, and the temperature of the water in the bowl. Add shavings of ice, or pounded ice, to the water, and when the temperature is steady again notice the position on the top of the water. Continue the cooling with ice, making observations of the position of the surface for about every three degrees down to 1° C. Then let the water in the bowl gradually rise in temperature, adding a little warm water, if necessary, and again observe the positions at the same temperatures as before. The mean of the two positions observed for each temperature should be taken as the true reading for that particular temperature.

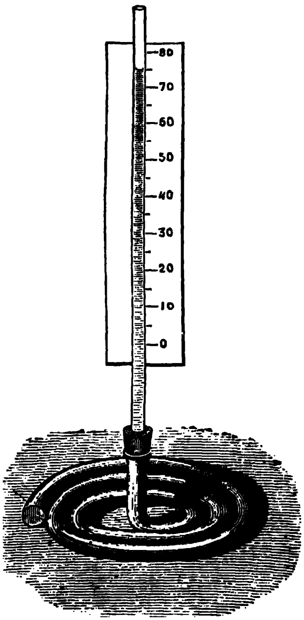

Fig. 93.—Arrangement for observing the anomalous expansion of water.

At what temperature has the water in the coil the least volume, and therefore the maximum density?

(*b*) The changes in volume of water, when cooled down to freezing point, can also be observed by means of a test-tube of water having a good stopper, with a narrow glass tube in it instead of the coil used in the preceding exercise. But as the expansion of water between 4° C. and 0° C. is very small, the experiment has to be carefully performed to be successful.

Changes in volume and density as water is cooled.—It has already been learnt that if the volume of a body gets greater while its mass remains the same, what is called the density of

the body must get less and less. It is quite clear that, if the same amount of matter occupies a larger space, it must be less closely packed into that space, and it is the closeness with which matter is packed into a space which we have learnt to call density. What changes in density take place when water is gradually cooled? Since we have seen in our experiments that the same mass of water gradually gets smaller and smaller in volume as it is cooled down to 4° C., we can also express the same fact in another way and say that its density becomes greater and greater as it is cooled down to 4° C. As from this temperature it gets larger as we continue to cool it, its density must get less and less. On the contrary, if we began with water at 1° C. and gradually warmed it, the density would steadily increase up to 4° C., and from that temperature upwards the density would regularly diminish.

Graphic representation of results.—A simple way of graphically showing the changes in volume which water undergoes when cooled is seen in Fig. 94. The water is represented as contained in a thermometer tube and the level of the water in the tube for each degree of temperature between 8° C. and 0° C. is shown. A glance makes the results of the experiments very plain. The size of the water is seen to get smaller down to 4° C. and then to begin getting larger, which it continues to do up to 0° C. So, too, the water is at once seen to be packed into a smaller space and consequently to get denser and denser as it is cooled down to 4° C., and then to become less dense as the lowering of temperature is continued.

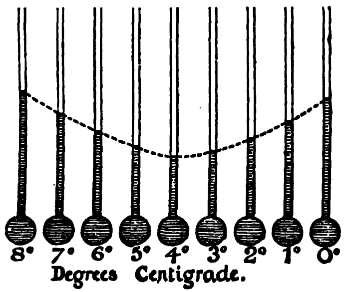

FIG. 94.—Changes in the volume of water between 8° C. and the freezing point.

Maximum density of water.—Because any mass of water has a smaller volume at 4° C. than at any other temperature, or, what is the same thing, has a greater density at this than any other temperature, we speak of 4° C. as being the temperature at which water has its maximum density.

Hope's apparatus.—An experiment with what is known as Hope's apparatus shows very well that water is at its maximum density at 4° C. A cylinder provided with two side necks in the way shown in Fig. 95 is filled with water at the same temperature as the air. Into the side necks, corks with thermometers passing through them are fitted. A freezing mixture, which can be made by mixing salt with pounded ice, is applied to the middle of the cylinder. This is done by filling a vessel, fixed round the middle of the outside of the cylinder, with the mixture in a way which the illustration makes quite clear. The freezing mixture, of course, at once cools the water in the middle of the cylinder. On watching the thermometers it is found that the first effect of the cooling is to cause the temperature of the lower thermometer to fall. The temperature of the upper thermometer, however, remains unaltered. The only way in which this can be explained is by supposing that as the water in the middle of the cylinder is cooled it gets colder and sinks to the bottom. As the cooling proceeds it is found that the water at the bottom of the cylinder *never gets below* 4° C. But soon after the water at the bottom of the cylinder has reached 4° C., the temperature of the upper thermometer begins to fall and goes on getting lower till it actually reaches 0° C. But all this time the water at the bottom remains at 4° C. Now it is quite clear that the densest water will sink to the bottom, and as the temperature of the water there remains at 4° C. it may be concluded that water at this temperature is denser than any other.

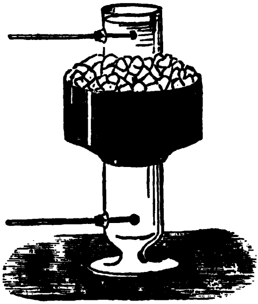

FIG. 95.—Hope's apparatus for the observation of the temperature of maximum density of water.

These considerations are summed up in the statement that *water at a temperature of 4° C. expands whether it is heated or cooled.*

Results in nature of the peculiar expansion of water.—From the results of an experiment with Hope's apparatus, or a consideration of the expansion and contraction of water, it is easy to understand what happens when the water of a pond is

gradually cooled on a frosty night. As the temperature of the water at the surface gets lower and lower, the water there gets smaller and consequently denser. It therefore sinks and its place is taken by warmer water from below. The same cooling and sinking of the surface water continues until the temperature of the whole of the water is 4° C., at which temperature it has its maximum density, and consequently when the water at the bottom of the pond reaches this temperature it remains where it is. After the temperature of the water at the surface has reached 4° C., any further cooling causes it to expand and get lighter, and this result continues until 0° C. is reached and the water at the surface is changed into ice, which, being considerably lighter than water, remains on the surface. Ice is, moreover, a very bad conductor of heat, and consequently the temperature of the water below the ice gets cooler very slowly and the thickness of the ice increases at but a small rate.

This condition of things prevents several disastrous consequences which would of necessity follow if ice were denser than water. If ice were denser than water, it would sink to the bottom of the pond at the moment it was formed, and as the frost continued, the ice would spread throughout the mass of the water, and not only would this result in the destruction of all the water animals in the pond, but it is more than probable that the heat of summer would be insufficient to completely melt it.

CHIEF POINTS OF CHAPTER VIII.

Effects of heat.—(1) Change of size. (2) Change of state. (3) Change of temperature. Change of size is known either as *expansion* or *contraction*. The former is generally brought about by heating, the latter by cooling.

Expansion and contraction by heat must be taken into account in (*a*) laying railway lines, (*b*) fixing steam or hot-water pipes, (*c*) building bridges. It is utilised in fixing iron tyres to wheels.

Choice of materials to be used in a thermometer.—(1) The substance used should expand a great deal for a small increase of temperature. (2) If a liquid is used it should not change into a solid unless cooled very much, nor into a gas unless heated very much. (3) The liquid should be in a fine tube with a comparatively large bulb at the end.

Reasons why mercury is used for thermometers.—In addition to the reasons above, (*a*) its level can be easily seen; (*b*) it does not wet the vessel in which it is contained; (*c*) it expands a considerable

amount for a small increment of temperature; (*d*) it is a good conductor of heat; (*e*) very little heat is required to raise its temperature.

The fixed points on a thermometer.—(1) The temperature at which ice melts or water freezes; (2) the temperature of the steam issuing from boiling water when the barometer stands at 30 inches.

Thermometric scales.—The distance between the freezing and boiling points on the stem of a thermometer may be divided as follows:

	Fahrenheit scale.	Centigrade scale.	Réaumur scale.
Boiling point,	212°	100°	80°
Freezing point,	32°	0°	0°

Changes in volume as water is cooled.—Water steadily contracts as it is cooled to 4° C. If the cooling is continued below 4° C., the water begins to expand, and does so until 0° C. is reached.

The density of the water in the same circumstances increases until 4° C. is reached, from which temperature it diminishes as the cooling proceeds; 4° C. is known as the temperature of *maximum density of water.*

Water at a temperature of 4° C. expands whether it is warmed or cooled.

In its conversion into ice, water expands very much and with great force.

EXERCISES ON CHAPTER VIII.

1. What is a thermometer, and what information concerning heat does it supply?

Give an instance of each of the following effects produced by heat: (*a*) change of size, (*b*) change of temperature, (*c*) change of state. (P.T., 1897.)

2. How would you test whether the two fixed points on a mercurial thermometer were accurately marked?

What would be the effect on the values obtained for the fixed points of the presence of common salt as an impurity in the materials used in determining these points? (1898.)

3. A flask containing pure water is heated by a single burner and one thermometer is placed with its bulb below the surface of the water, and another thermometer with its bulb just above the surface. When the water boils the readings of the two thermometers are taken. Will the readings be the same?

What will be the effect on the reading of each thermometer (1) of placing a second burner under the flask, and (2) of dropping some common salt into the flask? (1898.)

4. Describe carefully the manner in which the freezing and boiling points on a thermometer are determined. (1897.)

5. Take a glass tube open at one end and having a bulb at the other. Hold the tube so that the open end dips into water. Heat the bulb gently with a spirit lamp for a minute or two, and then take the lamp away. What will be observed? How can you account for the facts observed? (P.T., 1898.)

6. Mention conditions that should be satisfied by the bulb and tube of a mercury thermometer. Give the reason for each condition that you state. (P.T., 1898.)

7. I take two equal flasks, the mouths of which are fitted with bored corks carrying long glass tubes, and fill one with water coloured blue, and the other with methylated spirits coloured red; I then plunge them both into boiling water. Explain what will take place, giving reasons. (1900.)

8. How can the heights of mountains be determined by means of a *thermometer*, a flask of water, and a spirit lamp? (1900, Day.)

9. Describe carefully how to construct a common thermometer. (London Matriculation, January, 1899.)

10. What do we mean by the "boiling point" of a liquid? Explain why good tea cannot be made at the top of any very high mountain. (P.T., 1898.)

11. What do you understand by the temperature of maximum density of water? How has this temperature been determined?

12. A vessel of water at the freezing point contains two small glass bulbs. One is at the bottom, the other floats, but is almost wholly below the surface. The water is gradually heated; soon the bulb that was at the bottom rises, but after a while sinks again, and remains sunk. What is the meaning of this behaviour? How will the other bulb behave during the heating of the water? (L.C.C. Int. Sch., 1900.)

13. Describe how you would graduate a thermometer. Would any correction be necessary if you did it on the top of a mountain, or at the bottom of a coal mine? (Junior Oxford Local, 1900.)

CHAPTER IX.

QUANTITY OF HEAT AND ITS MEASUREMENT.

34. QUANTITY OF HEAT IN RELATION TO TEMPERATURE AND MASS.

i. **Distinction between temperature and heat.**—Place a can or beaker containing water over a burner. Place in the can a small test-tube containing water. After the can has been heated for a little time, observe the temperature of the water in the test-tube and surrounding it; it will be the same. Take away the burner, and lift the test-tube out of the can. You now have a small quantity of water and a larger quantity both at the same temperature; but there is more heat in the large amount than in the small amount. Prove this by pouring the hot water from the test-tube, and that from the can, into the same quantity of cold water from the tap in separate beakers. The large amount of hot water will thus be found to have a greater heating effect than the small amount; hence it must have possessed more heat than the small amount.

ii. **Result of mixing equal hot and cold masses of the same substance.**—(*a*) Put a certain mass of warm water in a beaker, and the same mass of cold water in another beaker. Observe the temperature of each by means of a thermometer. Pour the cold water into the hot. It will be found on stirring them together with the thermometer (taking care not to break the thermometer), that the temperature of the mixture is midway between the two original temperatures.

(*b*) Mix warm mercury at a temperature of say 50° C. with an equal mass of mercury at the temperature of the room. Notice that the resulting temperature is about midway between the temperatures of the two quantities of mercury.

You will probably find that the temperature of the mixture will not be exactly midway between the temperatures of the hot and cold liquids, because a little heat will be lost while the liquids are mixing.

(*c*) From the observations construct a table like the one below, to show that the temperature, produced by mixing equal masses of the same liquid at different temperatures, is equal to half the sum of the temperatures:

Temperature of Water *A*.	Temperature of Water, *B*.	$\frac{A+B}{2}$.	Temperature of Mixture.

iii. **Equality of loss and gain of heat.**—(*a*) Weigh about 200 gm. of cold water into a beaker, and observe its temperature. Put the same mass of water into another beaker; heat it to about 45° C. Now place the beaker of hot water on your table, with a thermometer in it, and observe its temperature. When the temperature has fallen, to say 40° C., take hold of the beaker with a duster, and quickly pour the hot water into the cold. Stir up the mixture with the thermometer, and observe the temperature after mixing. Record your observations as below:

Mass of cold water, - - - - ......gms.
Temperature ,, - - - - ......° C.
,, of mixture, - - - ......° C.
Number of degrees through which the temperature of the cold water was raised, - - - - - - ......° C.
Mass of hot water, - - - - ......gms.
Temperature of hot water, - - - ......° C.
Number of degrees through which the temperature of the hot water fell, - ......° C.

Tabulate the gain and loss of heat that occur, as shown below:

Gain.	Loss.
Mass of cold water × its rise of temperature	Mass of hot water × its fall of temperature
.........×.................	.................×.........
....	....

The gain will be found to be slightly less than the loss. This is not really the case, and it only appears so because the amount of heat required to raise the temperature of the glass of the beaker containing the cold water has not been taken into consideration.

(*b*) Repeat the experiment, using unequal masses of hot and cold water. Notice that in each case the mass of hot water × the fall of temperature is approximately equal to the mass of cold water × the gain of temperature. The difference shows the amount of heat absorbed by the glass of the cold beaker.

The amount of heat gained by 1 gram of water when its temperature is raised 1° C., or lost when its temperature falls 1° C., is adopted as the unit quantity of heat.

Difference between heat and temperature.—Temperature is not heat; it is only a state of a body, for the body may be cold one minute and hot the next. A hot body is one at a high temperature, a cold body one at a low temperature. If a hot

body and a cold body are brought into contact there is an exchange of heat until they are both of the same degree of hotness or coldness, that is, at the same temperature. Hence, temperature may be defined as *a condition or state of a body which is changed by the gain or loss of heat.*

Analogy of temperature with water level.—It is well known that if two vessels containing water and arranged at different levels are connected by means of a piece of india-rubber tubing, there is a flow of water from the vessel of water at the higher level towards the vessel at a lower level. This is a consequence of a property possessed by all liquids which makes them, as we say, "*seek their own level.*" This flow of water continues until the water in the two vessels is at the same level. Evidently this is a similar state of things to that which we have in the case of a hot and cold body in contact. In one case there is a flow of water until the level is the same in the two vessels. In the other there is a passage of heat until the temperature of the two bodies is the same. *Temperature corresponds to water-level.*

Temperature changes when hot and cold liquids are mixed.—Temperature may be regarded as heat-level, so that a hot substance is at a higher heat-level than a colder one. Now suppose that a certain mass of hot water is put into one vessel and an equal mass of cold water into another. We shall then have equal masses of water at different heat-levels. If the two liquids are mixed together, the temperature or heat-level of the hot water will fall, and the temperature of the cold will rise. The loss of level of one will be equal to the gain by the other, so that the temperature of the mixture will be midway between the two original temperatures. Thus, if the masses of water are equal, and the temperatures at first are 60° C. and 20° C., then the temperature of the mixture will be 40° C. The temperature of the hot water would fall 20° C. and the temperature of the cold water would rise 20° C.

The actual temperature of the mixture would be slightly less than the calculated temperature, because some heat would be lost while the liquids were being mixed. The loss may be regarded as a leakage of heat, and it would of course reduce the heat-level of the mixture in the same way that a leak in a water-level apparatus would cause the level after mixing to be less than it would be if the apparatus were perfect.

Quantity of heat in water at different temperatures.—*Quantity of heat may be measured by heating effect, so that we can say that the quantity of heat in a vessel of water depends* upon the *mass* of the water and its *temperature*. For any temperature, say 60° C., the amount of heat in 100 grams of water is twice as great as in 50 grams of water. In a similar way, the amount of heat in 100 grams of water at 40° C. is twice as great as in 100 grams at 20° C. When equal or unequal masses of water at different temperatures are mixed, the quantity of heat lost by the hot water is the same as the quantity gained by the cold water. The fall of temperature multiplied by the mass of hot water is equal to the rise of temperature multiplied by the mass of cold water.

Unit quantity of heat.—Now that it has been shown that we may correctly speak of quantities of heat, it is time to consider how such quantities of heat are measured. As in all other cases of measurement, a unit or standard quantity is required with which to compare quantities of heat. The unit quantity of heat generally adopted is the *amount of heat necessary to raise the temperature of one gram of water through one degree Centigrade.* This unit is called a *calorie* or *therm.* The amount of heat required to raise the temperature of 2 grams of water through 1° C. is thus 2 units or 2 calories. Similarly, if 1 gram of water at 0° C. is heated in a test tube over a burner until its temperature is 1° C., it will have received from the burner 1 unit of heat, or 1 calorie. When this 1 gram of water reaches a temperature of 3° C. it will have received 3 units of heat. If the tube contains 10 grams of water at 0° C., and its temperature is raised to 12° C., it will have received 10 times 12 units of heat, the number of units being equal to mass (in grams) × increase of temperature (in degrees Centigrade).

It will thus be seen that the number of units of heat taken up by any mass of *water* as its temperature rises, or the amount given out by any mass of *water*, the temperature of which is falling, may be found by multiplying the number of grams of water used by the number of degrees, as measured by a Centigrade thermometer, through which the temperature rises or falls. This rule may be written as follows:

Number of heat-units = Mass of water in grams × Number of degrees Centigrade through which its temperature rises or falls.

35. QUANTITY OF HEAT IN RELATION TO SUBSTANCE AS WELL AS TO TEMPERATURE AND MASS.

i. **The same quantity of heat may produce different changes of temperature.**—Weigh out equal masses of water and turpentine at the same temperature in two beakers of the same size. Pour equal quantities of hot water at the same temperature into the cold water and turpentine. Observe the rise of temperature produced in each case. Though the equal amounts of hot water contain the same quantity of heat, the rise of temperature of the turpentine will be found to be more than the rise of temperature of the cold water; in other words, the *capacity of turpentine for heat* is less than the capacity of water for heat.

ii. **Comparison of rates at which water and mercury gain heat.**—Weigh out equal masses of cold water and mercury at the same temperature in two test tubes or flasks. Support the two vessels side by side at the same distance above a flame, or in a large beaker of boiling water. Let them remain for a few minutes; then observe their temperatures. The rise of temperature of the mercury will be found to be greater than the rise of temperature of the water; in other words, mercury gets hotter than water under the same conditions.

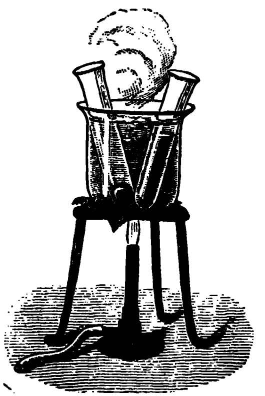

FIG. 96.—Equal masses of water and mercury do not become hot at equal rates, though they both have the same opportunity.

iii. **Different quantities of heat in equal masses of different substances at the same temperature.**—Place equal masses of lead and water in test-tubes standing in the same beaker, and heat them over a laboratory burner until the water boils; the temperature of both the lead and the water will then be about 100° C. Provide two beakers containing equal masses of cold water at the temperature of the room. Put the hot lead into one of these and the hot water into the other. Stir both mixtures and note the temperature in each case. The water into which the heated lead is plunged is not at so high a temperature as that into which the hot water is poured.

Equal amounts of water at the same temperature are thus shown to be heated to different degrees by equal amounts of lead and water at the same high temperature.

iv. **Capacity for heat.**—Place some iron nails in a beaker, and the same mass of cold water in another beaker. Let the two beakers stand for a while so as to assume the temperature of the room. Boil water in a kettle or other vessel, and pour equal quantities into the two beakers. Observe the temperature of the mixture in the

two beakers. The iron nails will be found to be hotter than the water in the other beaker, because iron takes less heat to raise its temperature than is required by an equal mass of water at the same temperature.

v. **Differing capacities for heat.**—Take balls of different metals of, say, lead, iron, tin, bismuth, with hooks attached; also a cake of bees-wax about ¼ in. thick, and arrange it on the ring of a retort stand. Then suspend the balls from a wire support in a bath of oil heated to about 150° C., and drop them together on to the cake of wax; notice the iron ball melts through first, then the tin, followed by the lead, and last of all the bismuth.

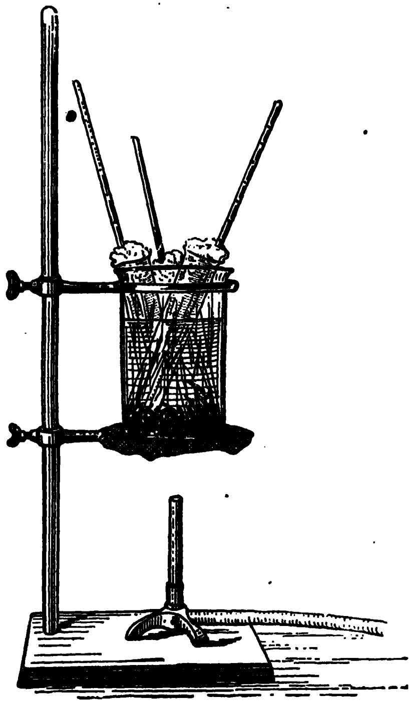

FIG. 97.—Method of heating metals in test-tubes for the determination of their capacity for heat. Each test-tube has a loose plug of cotton wool at the top. (From Rintoul's *Practical Physics*.)

vi. **Heat capacity of iron and other metals.**—(*a*) Weigh out about 50 grams of cold water and observe its temperature. Put into a test-tube an equal mass of iron tacks; stand the test-tube, with a thermometer surrounded by the tacks, in a beaker of water, and boil the water (Fig. 97). Observe the temperature of the tacks, and when the water has been steadily boiling for some time, take out the thermometer and cool it under the tap. Quickly pour the heated tacks into the cold water, and observe the temperature of the mixture. Notice that it is not so high as when hot water is added.

(*b*) Perform similar experiments, using (1) 50 grams of thin copper wire cut into pieces, (2) 50 grams of lead shot, (3) 50 grams of quicksilver, instead of the iron tacks in the last experiment.

Comparison of heat quantities.—It has been seen that the quantity of heat in water depends upon the mass of the water

and its temperature. It might be supposed, therefore, that as any mass of water at a certain temperature contains a certain quantity of heat, the same mass of another substance at the same temperature contains the same quantity of heat. This, however, is not the case. 100 grams of water at a temperature of 50° C. always contain 5000 units of heat, but 100 grams of turpentine, mercury, lead, iron, or any other substance at the same temperature as the water, namely 50° C., do *not* contain this number of units of heat. The quantity of heat in a substance thus not only depends upon the mass and the temperature, but also upon the substance itself.

Analogy between fluid capacity and capacity for heat.—If three jars of different diameters but equal heights are obtained, and a cup of water is poured into each, the water will be at different levels, as shown in Fig. 98. The same amount of water thus produces different changes of level, according to the vessel into which it is poured. In the narrow jar, which is a vessel of small *capacity*, the rise of level produced by the cup of water is much more than in either of the other jars, which are capable of holding much more water, and are, therefore, said to have larger capacities.

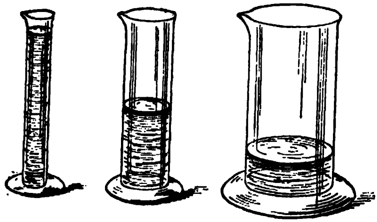

FIG. 98.—Jars of different capacity to illustrate that the same amount of water produces different levels.

Now, just as the same quantity of water produces different levels in vessels of different liquid capacities, so the same quantity of heat produces different heat-levels, or temperatures, in equal masses of substances of different *heat capacities*. If some hot water is poured into a cup containing cold water, the cold water rises to a certain degree of warmth; but if the same mass of hot water is poured into a cup containing cold turpentine of the same mass and temperature as the cold water, the mixture of water and turpentine becomes warmer than the mixture of hot and cold water, because turpentine has a smaller capacity for heat than water.

Capacity of water for heat.—Of all known substances, water

has a greater capacity for heat than any other body. Consequently a larger amount of heat is required to raise the temperature of a given mass of water through any number of degrees than is needed by an equal mass of any other substance.

Thus, suppose a pound of water be put into one flask and a pound of mercury into another, and that these flasks are then heated for five minutes by two laboratory burners, which, as far as we can tell, give out the same quantity of heat. The temperature of the two liquids at the commencement of the experiment is, say, 15° C. If at the end of the experiment the temperature of the water was 20° C., that of the mercury would probably be about 180° C., and in order to raise the water to this temperature, if that were possible by this means, much more heat would be required. Similarly, and for the same reason, in cooling through any number of degrees of temperature a definite mass of water will give out a larger amount of heat than an equal mass of any other substance, the temperature of which falls through the same number of degrees.

Results in nature of high capacity of water for heat.—The results in nature of this great capacity for heat which water possesses are very important.

Though water takes a large amount of heat to warm it and is consequently heated by the sun's rays only slowly, yet when it cools it parts with its heat just as slowly. The effect of this on the climate of islands is very marked. The winter temperature is never very low, and the climate never very severe, because the water surrounding the country not only acts like a great coat, and keeps the land warm, but also acts as a great storehouse, slowly giving up heat to it. Similarly, the summer temperature is never unbearably hot, because the surrounding water takes so long to warm, and, being always cooler than the land, keeps the temperature of the latter from getting very hot.

Temperatures produced by mixing various hot and cold substances.—If equal masses of lead and water be heated to the same high temperature, say 100° C., and the lead be plunged into one mass of water at a lower temperature, say 20° C., and the hot water be mixed with another equal mass of water at 20° C., and the resulting temperatures in the two cases be determined, it is found that the temperature of the mass of cold water into which the hot water was poured is higher than that of the equal mass of cold water into which the lump of lead was

plunged. Hence, equal masses of lead and water at the same high temperatures cannot give out the same amount of heat when cooled, because they contain unequal amounts. The water at 100° C. contains a larger quantity of heat than an equal mass of lead at 100° C., because its capacity for heat is greater.

Or, if 1 lb. of water at the temperature of the air be mixed with 1 lb. of iron at 100° C., the resulting temperature is not so high as that obtained by mixing 1 lb. of water at 100° C. with 1 lb. of iron at the atmospheric temperature. This evidently means that 1 lb. of water at 100° C. contains more heat than 1 lb. of iron at 100° C., or the capacity of iron for heat is less than that of water. In the same way, similar experiments with water and mercury show that the capacity of mercury for heat is less than that of water.

Comparison of capacities for heat of different metals.—When equal masses of water, tacks, copper-wire, and mercury at the same high temperature, that of boiling water, for instance, are each in turn stirred up with equal masses of cold water at the same temperature and in separate beakers, it is found that the hot water raises the temperature of the mass of cold water in which it is placed through a larger number of degrees than any of the other substances raises the temperature of the mass of water into which it is placed. This is because the capacity for heat of water is greater than that of any of these (or any other) substances.

If the temperature is observed of the mixture formed in each of the cases supposed, namely, tacks and water, copper-wire and water, and so on, and then the number of degrees through which each has raised the temperature of the water into which it was put is calculated, a series of numbers is obtained which enables a comparison to be made of the capacities for heat of each of the substances experimented with. The substances arranged in the order of their capacities for heat stand thus:

Iron (tacks)
Copper-wire
Mercury
Lead.

The amount of heat required to raise the temperature of one gram of a substance through 1° C. or the amount of heat given out by one gram of a substance the temperature of which falls through 1° C., in comparison with the amount of heat taken up

(or given out) by an equal mass of water, is known as the *specific heat* of the substance.

Relative heating effects of substances at the same temperature.—If balls of lead, iron, tin, and bismuth are heated to the same high temperature in a bath of oil and placed together on a cake of bees-wax, they melt through at different rates. The rate at which they melt through the wax depends chiefly upon the amount of heat they give out; so that since the iron gets through first it had most heat to give out, or its capacity for heat is greatest of all the metals taken. The experiment teaches, therefore, that the different metals have different capacities for heat. Though these bodies were at the same temperature, the amounts of heat they took up from the oil differed because of their different capacities for heat, and in the same way the amount of heat they are able to give to the wax also differs in the same proportion.

CHIEF POINTS OF CHAPTER IX.

Temperature may be defined as a condition, or state, of a body which is changed by the gain or loss of heat. It corresponds to water-level, and may be regarded as heat-level.

The unit quantity of heat is the amount of heat necessary to raise the temperature of one gram of water through one degree Centigrade. This unit is called a *therm*, or a *calorie*.

To ascertain the number of heat-units taken up or given out by a mass of water we may say:

Number of heat-units = Mass of water in grams × Number of degrees Centigrade through which its temperature rises or falls.

The capacity for heat of a substance is analogous to the capacity of a vessel for fluids. Water has a greater capacity for heat than any other substance. Its high capacity for heat has a profound influence on the climate of islands.

In determining the number of heat-units in a substance, its capacity for heat must be taken into account as well as its mass and its temperature. In fact:

Number of heat-units = Mass of substance × its temperature × its capacity for heat.

The specific heat of a substance may be defined as the amount of heat required to raise the temperature of one gram of the substance through 1° C. Or, the amount of heat given out by one gram of a substance the temperature of which falls through 1° C., in comparison with the amount of heat given out by an equal mass of water the temperature of which falls through 1° C.

EXERCISES ON CHAPTER IX.

1. If a pound of water at 100° C. is mixed with a pound of water at 0° C., the temperature of the mixture is 50° C. How would the result have differed if a pound of oil at 100° C. had been substituted for the hot water? Explain the difference. (1897.)

2. Explain what is meant by specific heat. How would you show that equal weights of different substances give out different amounts of heat when cooled through the same range of temperature? (1897.)

3. What is the difference between temperature and quantity of heat?

What experiments would you perform to show that equal masses of different substances when cooled through the same range of temperature give out different quantities of heat? (1898.)

4. Describe a differential air thermometer. How would you use one to investigate whether equal volumes of two different substances give out equal amounts of heat when cooled through the same range of temperature? (1897.)

5. What is the capacity for heat of a body?

Which has the greater capacity for heat, 5 c.c. of mercury, or 2 c.c. of water? [Specific gravity of mercury, 13·6; specific heat, ·033.] (Junior Oxford Local, 1900.)

6. Describe an experiment to show that equal masses of different substances at the same temperature possess different numbers of units of heat.

7. What influence has the water of the ocean on the climate of a country like Ireland?

8. Carefully explain the two statements:

(*a*) The specific heat of mercury is ·033.

(*b*) Water has a greater capacity for heat than any other substance.

9. What is wrong in the following statement: "Climate is determined by heat, moisture, and wind. The heat depends mainly on latitude and height"?

10. What will be the temperature of the mixture produced (supposing no heat to be lost) by mixing—

(*a*) 1 lb. of water at 10° C. with 3 lbs. of water at 70° C.?

(*b*) 1 lb. of quicksilver at 15° C. with 1 lb. of mercury at 95° C.?

CHAPTER X.

CHANGE OF STATE AND TRANSFERENCE OF HEAT.

Change of State.—It has been explained in Chapter I. that substances exist in three states, namely, solid, liquid, and gaseous. By the action of heat a substance may be changed from one state to another. Wax, for instance, is usually a solid, but by heating it becomes a liquid. Butter can in the same way easily have its state altered from solid to liquid. Lead and zinc are also melted when heated, but they require a hotter flame than wax or butter.

A good example of the changes of state produced by heat is obtained by heating a piece of ice until it becomes water, and then heating the water until it passes off into steam or water vapour. Here the same form of matter is by heat made to assume three states; in other words, ice, water, and steam are the same form of matter in the solid, liquid, and gaseous state respectively.

Change of state includes changes in the physical condition known as liquefaction or becoming liquid, and vaporisation or becoming converted into vapour. Thus, if we heat ice it first liquefied or becomes water, and is then vaporised or becomes steam.

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36. LIQUEFACTION.

i. **Melting point of wax.**—Melt a little paraffin wax in a beaker, and immerse the bulb of a thermometer in the liquid. When the thermometer is taken out, a thin film of liquid paraffin will be seen upon it. Let the bulb cool, and notice the temperature when the wax assumes a frosted appearance, which shows that it is solidifying. When the wax on the bulb has become solid, place the thermometer in a beaker of water and gently heat the water. Observe the temperature at which the wax becomes transparent again. The average of this result and the preceding one is the *melting point* of paraffin wax.

ii. **Melting point of butter.**—Place a little butter in a test-tube, and stand a thermometer in it. Place the test-tube in a beaker of

water, being gently heated on a sand-bath. Notice the temperature at which the butter melts. Take out the test-tube when the butter has all melted and let it cool. Notice the temperature at which it solidifies.

iii. **Melting point of ice.**—Put some small pieces or shavings of clean ice into a beaker and insert a thermometer into them. Record the temperature indicated. Pour in a little water, stir the mixture, and again record the temperature. Place the beaker on a sand-bath and warm it gently. Notice the reading of the thermometer *so long as there is any ice unmelted.* In all these cases the reading of the thermometer is practically the same, indicating that the temperature of melting ice is constant.

iv. **Heat required to melt ice.**—(*a*) Let a few lumps of ice stand in a beaker until some of them have melted. Notice that the temperature is 0° C. Counterpoise two empty beakers of the same size in the pans of a balance, and put a small lump of the ice into one, and the same mass of water from the melted ice in the other. You have thus equal masses of ice and water at 0° C. Pour equal masses of hot water into the two beakers. When the ice is melted, observe the temperature of the water in each beaker. The temperature of the water in the beaker in which the ice was placed will be found much lower than that of the water in the other beaker, owing to the ice using up a large quantity of the heat in melting into water.

(*b*) Take equal masses of hot water in two large beakers of the same size. Place a piece of ice in one of the beakers, and observe the temperature of the water when it has melted. Pour ice-cold water into the other beaker until the same temperature is reached. Find, by weighing, the masses of ice and ice-cold water which have been added. It will be found that a small mass of ice has as much cooling effect as a large mass of ice-cold water.

Temperature of melting.—When a solid is heated, the first effect is usually an increase of size. But if the heating is continued long enough, when the solid reaches a certain temperature, which differs from different solids, melting begins. The solid changes into a liquid. The temperature at which the melting takes place is called the *melting point.* Thus, when a lump of lead is heated its temperature rises, it gets larger, and as the heating is continued it is converted into a silvery-looking liquid. Wax, ice, and iron are other examples of solids which melt. But ice, wax, lead, and iron differ very widely in the temperatures at which they begin to melt, as the following table shows:

Ice	melts at	0° C.
Bees-wax	„	65° C.
Lead	„	330° C.
Cast-iron	„	1200° C.

So long as any of the solid remains unmelted, the temperature does not rise above the melting point. You can easily satisfy yourself that this is true in the case of ice. If you obtain some small pieces of clean ice, and thrust a Centigrade thermometer into them, you will notice that the thermometer records a temperature of 0° C. Or, if you put some of the ice into a beaker, and pour in some water, you will find after you have stirred the ice and water together for a little while, provided you have put enough ice to be sure that it does not all melt, that the thermometer still records a temperature of 0° C. And even if you put the beaker, with the ice and water in it, over a laboratory burner and warm it gently, you will still find that, so long as there is any ice unmelted, the thermometer still reads 0° C. It is very evident, then, that the temperature of melting ice is always the same, and remains the same so long as there is any ice unmelted.

Latent heat.—The experiments which have just been described are of the very greatest importance, and should be clearly understood. It is certain that when a mixture of ice and water is heated over a laboratory burner heat is being continually given to the mixture. Yet the temperature as recorded by the thermometer gets no higher. The question arises, what becomes of this heat, as it has no effect upon the temperature of the mixture? You know that the ice is gradually melted, and if the heating is continued long enough it is all changed into water. As soon as this has happened, every further addition of heat raises the temperature of the water. These considerations lead to the conclusion that the heat previously given to the mixture is all used up in bringing about the change of ice into water. Further, it is found that not only in the case of ice, but when any solid is turned into a liquid, there is no increase in temperature, even while heat is being added, until the whole of the solid has been changed to a liquid.

This amount of heat which is necessary to change a solid into a liquid is spoken of as *latent heat.* The word latent comes from a Latin word, meaning "lying hidden," and refers to the fact that the heat used up in changing a solid to the liquid condition has no effect upon a thermometer, but appears to be hidden away in the liquid.

Latent heat of water.—The number of units of heat which

are required to change the state of a gram of ice, converting it from the solid to the liquid condition without raising its temperature, is called the latent heat of water or the *latent heat of fusion of ice.* To melt 1 gram of ice requires 80 heat-units. That is to say, as much heat as would raise the temperature of a gram of water through 80° C., or would raise that of 80 grams of water through 1° C., is used up in changing a gram of ice into a gram of water at the same temperature. Similarly, to melt 1 lb. of ice requires as many heat-units as are necessary to raise the temperature of a pound of water from 0° C. to 80° C., or, as much heat as is wanted to raise the temperature of 80 lbs. of water through one degree Centigrade.

Natural consequences of latent heat of water.—Just as it is necessary before a pound of ice can be changed into a pound of water to pour into it an amount of heat which would raise the temperature of a pound of water through 80° C., so before a pound of water can be changed into a pound of ice, we must take from it precisely the same amount of heat. This is why it takes so many cold nights to cover a pond with ice, for not until every pound of water at the surface has had this large amount of heat taken from it can it change into ice. For just the same reason, it takes a very long time to completely melt the snow in the roads and the ice on the ponds, even after a thaw has set in.

37. VAPORISATION.

i. Cooling produced by evaporation.—(*a*) Sprinkle a few drops of spirits of wine, sal-volatile, or ether, on your hand in succession. Notice that the liquid soon disappears, and its presence in the air can be detected by its smell. The rate at which the liquid evaporates is increased by waving the hand about. The hand feels cold.

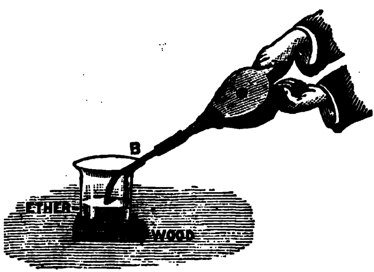

FIG. 99.—Experiment to show that water may be frozen by the rapid evaporation of ether close to it.

(*b*) Pour a few drops of water upon a dry piece of thin wood, and stand in the water a thin beaker containing a little ether. Blow vigorously down a tube having one end in the ether (Fig. 99), or use a pair of bellows.

The ether rapidly evaporates, and *in doing so takes heat from the water* between the beaker and piece of wood. The beaker and wood become frozen together.

ii. **Heat liberated when steam is condensed.**—(*a*) Put equal quantities of cold water into two beakers of the same size. Observe the temperature. Boil water in a flask with a delivery tube (Fig. 100), and pass the steam into the cold water in one of the beakers. When the temperature of the water has been raised about ten degrees, take away the delivery tube, pull the cork out of the flask, and pour enough boiling water into the other beaker to raise the temperature by the same number of degrees. Find, by weighing, the masses of steam and water added to the cold water in the two beakers. It will be found that a small mass of steam in condensing into water produces the same heating effect as a much larger mass of water.

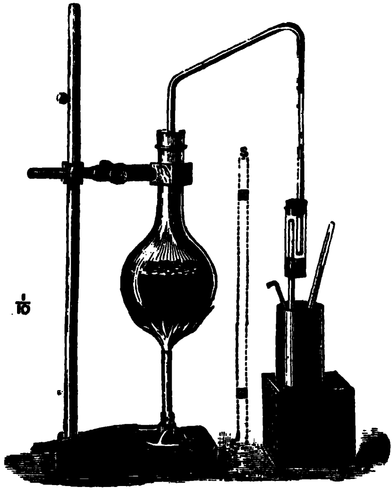

FIG. 100.—Flask fitted with tube and water-trap for passing steam into water; *S, S* is a screen.

(*b*) Compare in the same way the heating effect of equal masses of steam and boiling water. To do this pass steam into cold water and determine the amount condensed. Then add to a similar amount of cold water a quantity of hot water equal to the quantity of steam condensed.

Heat disappears during vaporisation.—When a liquid is changed into vapour a certain amount of heat is used up. It does not matter whether the liquid evaporates or boils; every gram of it requires a certain amount of heat before it becomes converted into vapour. In boiling, this heat is supplied by the flame or fire, and in evaporation it is taken from the objects in contact with the liquid. The faster the evaporation the more heat is absorbed in this way. When a liquid evaporates very rapidly, the cooling produced is very noticeable. For instance, if a few drops of either spirits of wine or ether are sprinkled upon the hand, the liquid soon disappears and the hand feels cold.

The heat necessary for the evaporation of these liquids is taken from the hand, or from any other things with which they are in contact, consequently the hand becomes cooler and cooler as the vapour is formed. So much heat may be absorbed in this way that, as illustrated by the experiment shown in Fig. 99, water can be frozen by the evaporation of ether in a vessel in contact with it.

In tropical countries, where the land gets *very hot* during the day, evaporation takes place so rapidly after sunset that the water sometimes becomes so much cooled by the extraction of the heat required to bring about the change from liquid to vapour, that the water freezes.

You will probably yourself have noticed that not only is the dust laid by watering the roads in summer, but the air is pleasantly cooled by the evaporation of the water.

Latent heat of steam.—You have noticed several times in different experiments that when once water has started to boil, its temperature gets no higher than the boiling point. As long as there is any water left, no matter how much you heat it, its temperature remains the same. After what has been learnt about the latent heat of water, you will have no difficulty in understanding the reason for this. All the heat is absorbed, or used up, in bringing about the change from the liquid state to that of vapour. It requires a great many more heat-units to convert one gram of water at a temperature of 100° C. into steam at the same temperature, than it does to change a gram of ice at 0° C. into a gram of water at 0° C. Whereas to bring about the latter change requires an expenditure of 80 heat-units, to convert a gram of water at 100° C. into a gram of steam without changing its temperature requires no fewer than 536 heat-units. Or, the *latent heat of steam*, or, as it is sometimes called, the *latent heat of vaporisation of water*, is 536. Expressed in another way, we may say that it requires as many heat-units as would raise the temperature of 536 lbs. of water through 1° C. to simply bring about the change of one pound of water at 100° C. into one pound of steam at the same temperature. It must also be remembered that a liquid is never changed into a vapour without some absorption of heat. This is true whether the change takes place quietly in evaporation or rapidly as in boiling.

Just as a large quantity of heat is required to convert water

into steam, so a large quantity is given up when steam becomes water. It is for this reason that a scald from the steam of boiling water is worse than a scald from the boiling water itself.

Summary of results.—The changes caused by heating ice until it is converted into steam may now conveniently be summarised. Beginning with a lump of ice at a temperature of 0° C., we know that it melts and changes into water at 0° C. when 80 units of heat have been supplied to every gram of it. After all the ice has been changed into water at 0° C., each successive addition of heat has two effects. First, the temperature is raised, and secondly, the size or volume of the water is altered. Whilst, however, the temperature rises regularly, the alterations in size are not regular; the size of the water gets smaller and smaller to begin with for every degree increase of temperature. This is continued until the temperature of 4° C. is reached, at which temperature the water has a smaller size than at any other, or is at its maximum density. From 4° C. onwards, the temperature and volume increase together as the water is more and more heated, and this holds true until a temperature of 100° C. is reached, when the water boils and is changed into steam. When once the water has commenced to boil the temperature remains at 100° C., or, as it is called, the *boiling point* of water, so long as any water is left. If steam is placed in an enclosed vessel away from water, its temperature can, of course, be raised above 100° C.; in this case, what is known as *superheated steam* would be obtained.

Graphic representation of the changes of volume and temperature accompanying changes of state of water.—These changes of volume and temperature are of such importance that it is worth while to impress them upon the mind by representing them graphically. One way of doing this is shown in Fig. 101. The temperatures are marked in Centigrade degrees along the bottom line of the diagram. The height of the shaded portion of the illustration at any point represents the volume at the temperature shown on the bottom line. Beginning at the left-hand of the figure, we are supposed to start with a lump of ice at −20° C., and to gradually warm it. Until the temperature reaches 0° C. the ice behaves like most other solids, and regularly expands as it is warmed. When the temperature of 0° C. is reached, though the heating

goes on steadily, the temperature does not alter. The heat is used up in changing the ice into water, and the volume of the water as shown by the height of the shaded portion of the figure is less than that of the ice. When all the ice is changed into water, the further addition of heat causes the increase of temperature up to 4° C., but, as the height of the shaded parts

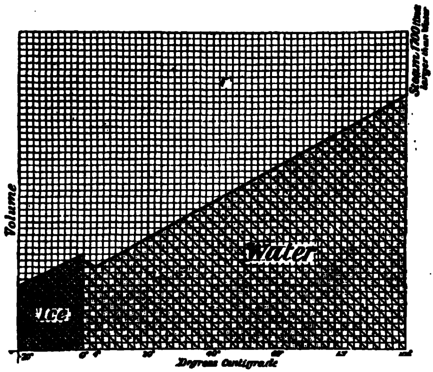

FIG. 101.—Graphic representation of changes of volume of water between −20° C. and 100° C.

shows, the volume gets smaller until this temperature is reached. From 4° C. to 100° C. the diagram shows temperature and volume increasing together. The temperature remains at 100° C. until all the water is changed into steam, and the size of the steam is 1700 times greater than that of the water at 100° C. from which it was formed.

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38. TRANSFERENCE OF HEAT. CONDUCTION.

i. Relative conductivities of metals.—Obtain wires or strips of copper, iron, brass, German silver, and of any other metals available. Let the diameters be the same as nearly as possible, and the lengths about 15 or 20 cms. Place the wires upon a clay tile or other suitable support, as shown in Fig. 102. Support the tile in a horizontal position and heat the wires with a flame where they meet. After a few minutes slowly move a safety match along each wire in succession, commencing at the ends away from the flame, and notice the points at which the matches will light. Repeat the experiment several times; then take away the flame and measure the distance of these points from the heated ends. Find the average distance for each wire.

The numbers obtained will show you the relative conducting powers of the metals of which the wires are composed. Write down these metals in the order of their ability to conduct heat, beginning with the best conductor, and putting against each name the average distance at which the match was ignited upon it.

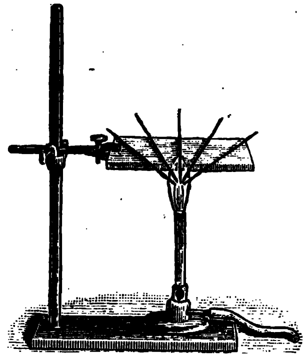

FIG. 102.—Experiment to show relative ability of metals to conduct heat.

ii. **Lowering of temperature by conduction.**—(*a*) Make a short coil of stout copper wire ¼-inch internal diameter. Pass it over the wick of a candle without touching the wick. The candle is extinguished owing to the cooling effect of the wire, which conducts away the heat.

(*b*) Turn on, but do not light, a gas jet. Hold over it a wire gauze, and light the gas above the gauze. Notice that the flame does not strike through. Why? Vary the experiment by lowering a piece of cold wire gauze upon an ordinary Bunsen flame. What happens?

iii. **Water is a bad conductor of heat.**—Fill a test-tube three-quarters full with cold water, and having weighted a small piece of ice by winding wire round it, or in some other way, drop it into the test-tube. Hold the test-tube near the bottom where the piece of ice is, and warm the top of the water in a Bunsen flame, as shown in Fig. 103. The water at the top can be heated until it boils vigorously and yet the ice is not melted, showing what a bad conductor the water is.

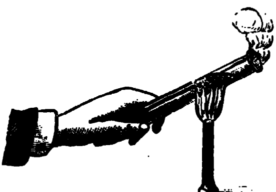

FIG. 103.—Illustration of the fact that water is a bad conductor of heat.

iv. **Gases are bad conductors of heat.**—(*a*) Examine the shadow of a red-hot poker. Notice that the heating of the air as exhibited by its flickering extends but a very little way downwards, thus showing that air is a bad conductor of heat.

(*b*) Place a little lime in the palm of the hand and bring the point of a hot poker upon it. The air enclosed in the lime does not conduct the heat of the poker, so the hand is not burnt.

Heat is transmitted in three ways.—Heat is transferred from one place to another in three ways:

1. Heat may pass from one particle of a body to the next, travelling from the hotter to the colder parts, and causing no

visible motion of the particles of the body. This mode of transference is called *Conduction*, and is the process by which solids are heated.

2. When the heated particles actually move from one part of the body to another, causing it to become warmer throughout, the process is know as *Convection*. Liquids and gases become heated in this way.

3. When the heat passes from one point to another in straight lines with great speed, without heating the medium through which it passes, it is said to be transmitted by *Radiation*. The heat of the sun is transmitted through space in this way.

Conduction of heat.—By touching a succession of things in a room, say the marble mantel-piece, the fender, the back of a chair, the hearth-rug, we obtain a succession of sensations; the first two we say are cold, the chair-back not quite so cold, while the rug feels quite warm, and yet they are one and all under the same conditions and there is no reason why they should not be at the same temperature. The explanation of these different sensations is really very simple. In all those cases where the hand *receives heat* we feel the sensation of warmth, while in those where the hand *gives out* heat we say the body is cold or cool. Fig. 104 will enable the student to remember this. Now we see why the fender feels colder than the hearth-rug. The fender takes more heat from the hand than the hearth-rug, and it does so because it is a better *conductor of heat*.

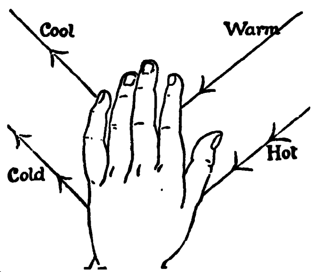

FIG. 104.—To illustrate how a thing feels hot, warm, or cold according to the gain or loss of heat by the hand.

We shall do well to consider this expression a little. Put one end of a poker in the fire and hold the other. Soon the poker begins to feel warm, and as time goes on it gets warmer and warmer, until at last you can hold it no longer. Heat has passed from the fire along the poker, or has been *conducted* from the fire by the poker.

The process by which heat passes from one particle of a body to

the next is called conduction, and the body along which it passes is known as a conductor.

Good and bad conductors.—Those substances which easily transmit heat in this way are called *good conductors*, while those which offer a considerable amount of resistance to its passage are called *bad conductors.*

Metals are, as a rule, good conductors of heat, but some metals conduct heat better than others. Most liquids are bad conductors of heat, though quicksilver, being a metal, is an exception. If liquids were heated only by conduction, water would boil throughout just as quickly when the source of heat was placed in contact with the top layer of liquid as it does when the heating takes place from below.

Gases are even worse conductors of heat than liquids, the everyday methods of taking the conducting power for heat of different substances into account are mostly applications of the very low conductivity for heat which air possesses.

Everyday uses of bad conductors.—To keep ice in the warm days of summer the custom is to wrap it up in flannel and put it into a refrigerator. The flannel, because of its loose texture, encloses a quantity of air, which, being a bad conductor of heat, prevents the passage of heat from the warm outside air to the cold ice inside. Similarly, ice which has to be conveyed by rail or boat is packed in sawdust.

The refrigerator itself, too, depends upon much the same facts. The common form consists of a double-walled box with a space between the walls. This is either left "empty," as it is called when it is full of air; or, it is filled with some other bad conductor, such as the mineral substance *asbestos.*

If we wish to lift a hot plate we hold it with a folded cloth for the same reason. Cylinders of engines are sometimes encased in a packing of some badly conducting material.

39. CONVECTION.

i. **Convection in a liquid.**—Heat over a small flame a round-bottomed flask full of water, as in Fig. 105. Throw into the water some solid colouring matter, like cochineal, aniline dye, litmus, etc. Notice how the hot, coloured water ascends.

ii. **Circulation of water.**—Fit up apparatus as shown in Fig. 106. *A* is a 6-oz. wide-mouth, corked bottle, with the bottom knocked out (a small gas jar will do, or an ordinary lamp glass may be used). A

well-fitting cork with two holes is inserted, through which the bent glass tubes *B*, *B′* pass, as shown. They are united at the bottom by a short piece of india-rubber tubing, *C*. Pour water into *A* until it just covers the open ends of the tubes. Now pour in about a tea-spoonful of ink. Apply a small flame at *B*. Notice what happens.

iii. **Convection currents in gases.**—(*a*) Place a short piece of candle in a saucer, light it, put a lamp glass over it, and pour sufficient water into the saucer to cover the bottom of the lamp glass (Fig. 107).

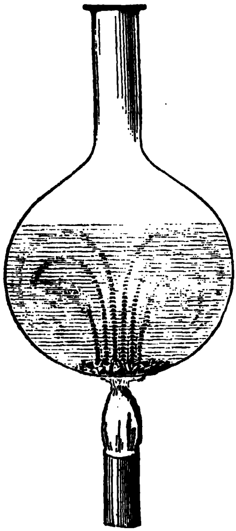

FIG. 105.—Convection currents in water.

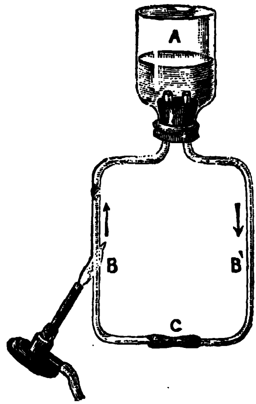

FIG. 106.—Circulation of water produced by heat.

Watch how the light of the candle is affected. Next cut a strip of card less than half the height of the lamp glass, and nearly as wide as the internal diameter of the top. Insert the card into the lamp glass so as to divide the upper part into halves. Now light the candle again, and see whether it will burn with the divided chimney over it. Test the direction of the currents of air at the top of the chimney by holding a smoking taper or match over it.

Process by which liquids are heated.—The process by which water and other liquids are heated may be easily studied by heating water into which some solid colouring matter, like cochineal, aniline dye, litmus, etc., has been thrown, in a round-bottomed flask over a small flame, as in Fig. 105. The water

nearest the flame gets heated, and consequently expands and gets lighter. It therefore rises, and causes a warm ascending current of coloured water. But something must take the place of this water which rises, and the cold water at the top, being heavier than the warm water, sinks to the bottom and occupies the space of the water which has risen. This water in its turn gets heated and rises, and more cold water from the surface sinks. This gives rise to upward currents of heated water and downward currents of cool water, until by-and-by the whole of the water is heated. These currents are known as *convection currents*, and the process of heating in this manner is called *convection*. Eventually the whole of the water gets so hot that the bubbles of vapour which are formed near the source of heat are not condensed again in their upward passage through the liquid, and coming to the surface they escape as steam.

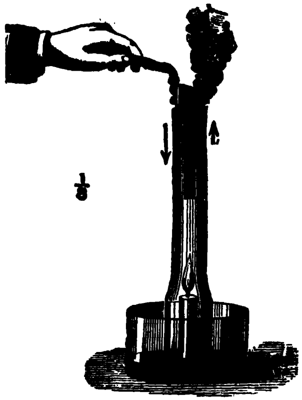

FIG. 107.—Convection currents in gases.

Gases are similarly heated by the process of convection, which may be thus defined :—*Convection is the process by which fluids (liquids and gases) become heated by the actual movement of their particles due to difference of density.*

Ventilation.—The ventilation of ordinary dwelling rooms is easily possible because of the way in which gases become heated by convection. The air in a room becomes warmed and rendered impure at the same time. Consequently there is a tendency for the impure air to rise, and if a suitable place near the ceiling is made for it to get out, as well as a place near the floor for the colder, purer air from outside to enter, a continuous circulation of air is set up which will keep the atmosphere of the room pure and sweet.

Another experiment is to place a short piece of candle in a saucer, light it, put a lamp glass over it, and pour sufficient water into the saucer to cover the bottom of the lamp glass (Fig. 107). In this case the light of the candle is affected and

eventually goes out. But if a strip of card is cut less than half the height of the lamp glass, and nearly as wide as the internal diameter of the top, and is inserted into the lamp glass, so as to divide the upper part into halves, and the candle is again lit, it will be seen to continue to burn with the divided chimney over it. The direction of the currents of air at the top of the chimney can be shown by holding a smoking taper or smouldering brown paper over the chimney.

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40. RADIATION.

i. **Heat transmitted by radiation.**—(*a*) Place a differential thermometer (Fig. 84) about a foot away from the flame of a laboratory burner so that both its arms and the flame are in one straight line. Notice that the bulb of the thermometer nearer to the flame is hotter than the one more remote. How does the heat of the flame travel to the thermometer?

(*b*) Arrange the bulbs of the thermometer a foot above the flame and observe the nearer bulb is warmed much more than before. The air in this case is heated by convection as well as radiation.

(*c*) When you have an opportunity, focus the rays of the sun upon the back of your hand by means of a reading glass. This can be done by placing the reading glass between the sun and the hand and moving the glass until the brightest image of the sun is obtained. Notice that the heat is very intense and burns you. Notice that the glass itself is not heated to the same extent.

ii. **Effect of surface upon radiation and absorption.**—(*a*) Obtain two small bright tin cans or canisters, and fit into each a cork having a hole through which a thermometer will pass. Cover the outside of one of the vessels with lamp-black by holding it over a candle or luminous gas flame, or over burning camphor. Put the same quantity of hot water at the same temperature in each, and then cork up the vessels, each cork having a thermometer through it so that the bulb is well immersed in the water. Observe the temperature of each vessel of water, and if the temperature of one is higher than that of the other, cool the vessel until the temperatures are equal. Then put the vessels in a cool place where there are no draughts, and after 20-30 minutes again read the temperatures.

The blackened vessel will be found to have lost or radiated more heat than the bright one.

(*b*) Similarly equally fill a blackened and a bright vessel with cold water of the same temperature, and hang them for 20-30 minutes at the same distance above an iron plate, supported on a tripod stand and heated by a laboratory burner. At the end of this time observe their temperatures.

The blackened vessel will be found at a higher temperature than the bright one, indicating that a lamp-black surface absorbs heat better than a bright metallic surface.

Radiant heat.—The experiments just described are sufficient to convince you that heat can travel from one place to another in a third way which is neither conduction nor convection. The respects in which radiation differs from the other ways in which heat moves from one place to another are: (1) it travels in straight lines, and (2) it does not warm the medium through which it travels. Although you may not have thought of the fact that radiation travels in straight lines, you have made use of it when you have screened your face from the heat of the sun or of a fire. When you wish to protect yourself from the glare of the summer sun you seek a shady space, because then some object, it may be a tree or a house, is in the straight line between you and the sun.

A reading glass is not warmed by the passage through it of the radiations from the sun. Evidently, then, while passing through the glass the radiations are not heat. Really, no radiation is heat. It is simply a wave-motion in the medium through which it passes. This medium is known as "ether," but it is in no way connected with the liquid ether used for scientific purposes. The ether is little more than a name, for, though something must exist to transmit waves of light and heat, nothing is known as to its constitution. It is only when certain ether waves are absorbed by material bodies that they give rise to heat. Those ether waves, which by absorption give rise to heat, are often spoken of as 'radiant heat,' but the name is wrong, as you will understand when you bear in mind that radiations are only wave-motions in the hypothetical medium which is supposed to fill the space between the outer limits of the earth's atmosphere and the sun, and also to exist throughout all forms of matter. To speak more accurately, we must say heat travels from one spot to another by radiation when (1) a body in one spot is sufficiently hot to cause wave motions in the ether surrounding it, (2) these are transmitted through the ether to (3) a second body which absorbs the wave-motion and becomes warmed. The subject of radiation is more fully dealt with in subsequent chapters.

CHIEF POINTS OF CHAPTER X.

Melting point.—The temperature at which a solid changes into a liquid is called its *melting point*.

Latent heat.—The amount of heat necessary to change a solid into a liquid at the same temperature, or the amount required to change a liquid into a gas at the same temperature, is known as *latent heat.*

Latent heat of water.—The number of heat-units required to convert one gram of ice at 0° C. into water at the same temperature is known as the *latent heat of water.* Its numerical value is 80.

Latent heat of steam.—The number of heat-units required to change one gram of water at 100° C. into steam at the same temperature is known as the *latent heat of steam.* Its numerical value is 536.

Heat is transmitted in three ways: (1) by conduction; (2) by convection; (3) by radiation.

Conduction is the process by which heat passes from one particle of a body to the next.

Solids are usually better conductors than liquids; liquids conduct heat better than gases.

Convection is the process by which liquids and gases become heated by the actual movement of their particles due to difference of density.

Heating buildings by hot water, and methods of ventilation are applications of heating by convection.

Radiation differs from conduction and convection in two ways: (1) it travels in straight lines; (2) it does not warm the medium through which it travels.

EXERCISES ON CHAPTER X.

1. A thin layer of water in a porous dish is placed out of doors at night in India, and in the early morning is found to be converted into ice. Explain the causes by which this result is brought about. (1900, A.)

2. I place on a piece of wood a vessel containing ether, having previously poured some water on the wood. State what occurs when I blow over the surface of the ether with a pair of bellows, and explain the several results. (1900.)

3. Suppose that it requires 80 times as much heat to melt one ton of ice as would be required to warm one ton of water one degree of temperature on the Centigrade scale, how much of the ton of ice would be melted by pouring into a cavity in its surface a gallon of boiling water? A gallon of water weighs 10 lbs. (London Matric., 1899.)

4. How would you propose to prove by experiment that to boil away a gallon of water requires about five times as much heat as is needed to raise it from the freezing to the boiling point? (London Matric., 1899.)

5. A beaker containing a mixture of ice and water is heated by means of a flame, being kept well stirred all the time.

Describe how the temperature, as shown by a thermometer, of which the bulb is immersed in the contents of the beaker, will vary as the heating is continued, and give reasons for the peculiarities observed in the rate at which the temperature rises. (1898.)

6. When matter is transformed from the liquid to the gaseous state, what changes take place in its physical properties and the arrangement of its parts? Is the chemical constitution of the body altered by vaporisation? (1897.)

7. Four ounces of hot lead filings and four ounces of water at the same temperature are poured upon separate slabs of ice. Will the lead or the water melt more ice? Give reasons for your answer. (P.T., 1897.)

8. An ounce of water at 0° C. is mixed with ten ounces of water at 70° C. What is the temperature of the mixture?

An ounce of ice is dissolved in ten ounces of water at 70° C., and the temperature of the mixture is found to be something over 56° C. What can be learnt from this experiment? (P.T., 1898.)

9. What is meant by convection?

Illustrate your answer by sketches, taking the case of a vessel filled with water and heated from below and explain why it is that convection is set up. (1899, Day.)

10. Why is a vessel of water heated more quickly if heat is applied at the bottom than if it is heated at the top?

Draw a diagram to illustrate the movements of a liquid heated from below. (1897.)

11. Point out the difference between the conduction and convection of heat.

Describe an experiment showing that water is a bad conductor of heat. (1897.)

12. Water sometimes spurts from the spout of a kettle standing upon a fire. How do you account for this, and how would you prevent it without taking the kettle off the fire. (P.T., 1897.)

13. On a cold morning a gardener grasps the iron part of his spade with one hand and the wooden part with the other. Explain why one hand feels colder than the other. (P.T., 1898.)

14. If a spoon made of solid silver and one made of brass and only silver plated are placed in bowls in some boiling water, the handle of the silver spoon becomes much hotter than that of the plated one. Why is this?

Describe an experiment by which you would show that your explanation is correct. (1899.)

15. If a hot lamp-glass is touched with a cold knife blade it will often crack. If a tightly-corked bottle full of water is put out of doors on a frosty night it will burst. Explain as fully as you can the reasons of these two results. (1899, Day.)

16. How is the reading of a thermometer altered by wrapping a wet rag round the bulb? What will happen if the rag is wetted with (1) ether, (2) oil instead of water? How do you explain the various results? (Queen's Sch., 1899.)

17. Two test-tubes *A* and *B* are filled with water. A small piece of ice is allowed to swim in *A*, and a similar piece of ice is sunk by a weight to the bottom of *B*. Heat is applied to the closed end of *A* and to the open end of *B*. In which test-tube may we expect the ice first to melt? and in which may we expect the water first to boil? Give reasons for your answer. (Queen's Sch., 1899.)

CHAPTER XI.

PROPAGATION AND REFLECTION OF LIGHT.

Light is a form of radiation.—In considering, at the end of the previous chapter, the ways in which heat can be transferred from one place to another, it has been seen that the heat of the sun reaches the earth by radiation. These solar radiations comprise what is collectively called *sunlight*; they are conveyed in the form of *waves* through the medium *ether*, which is believed to pervade all space, and may be conveniently referred to as *ether-waves*. These ether-waves can produce different effects. If they fall upon our bodies they may be absorbed, and the energy of the wave motion become converted into *heat*; if they fall upon the retina of an eye, they may produce a sensation of light, and the waves are then spoken of as *light*; falling upon a photographic plate or upon a green leaf, the ether-waves may produce chemical effects, and are then referred to as *actinic*. But, in their passage through the ether, these ether-waves do not give rise to any of these effects; they are simply waves transferring energy by wave-motion.

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41. RECTILINEAR PROPAGATION OF LIGHT.

i. **Light travels in straight lines.**—Take three cards and make a small hole in each with a fine needle. Fix the cards upon wooden blocks, so that all the holes are at the same height and in a straight line. Place a lighted candle or a lamp in front of the card, and look through the third (Fig. 108). So long as the holes are in a straight line you can see the light from the candle shining through. Move one of the cards aside, and notice that you can no longer see the light. It must be remembered that what is true of light applies equally to all other kinds of radiation.

ii. **Pin-hole camera.**—Construct a pin-hole camera as follows: Make two pasteboard tubes by rolling pasted paper on a wooden cylinder, so that one fits inside the other. For the wider tube

previously cover the cylinder with dry paper. Cover one end of the narrower tube with tissue paper, and thrust this end into the wider

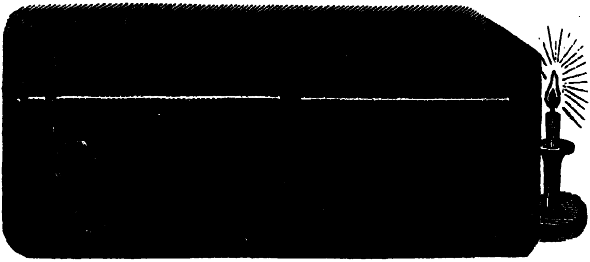

FIG. 108.—The light of the candle can only be seen when the three holes in the screens are in a straight line.

tube. Line with black paper. Place the tube with the pin-hole facing a luminous object, *e.g.* a candle. Notice that the image of the candle seen upon the tissue paper is upside down. Reason out how this image is formed. Many toy-shops sell a pin-hole camera at so low a price as a penny, and one of these may be used instead of constructing one from tubes.

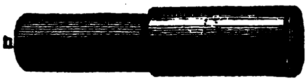

FIG. 109.—A simple pin-hole camera.

iii. **Overlapping of images.**—Make several pin-holes near the first one in the pin-hole camera. For every pin-hole there is an image formed on the screen. Make the pin-holes more and more numerous, and nearer together, till the images overlap and become confused. At last diffused light is produced, which is an overlapping of images. This experiment explains why the image becomes blurred, and eventually disappears if the size of the single pin-hole is increased.

Light travels in straight lines.—That light rays travel in straight lines can be at once shown by examining their paths as they pass through a hole in the shutter of a darkened room. Though the light-waves are not themselves visible, yet the path of the light becomes apparent, because the minute particles of dust in the air are rendered luminous by the vibrations of the ether being absorbed by them. If there were no dust particles in the room the beam of light would not be visible. When the path of a beam is made visible by smoke or dust it is seen to be a straight line. That light travels in straight lines may, indeed, be inferred from several everyday experi-

ences. We cannot see round a corner; if light travelled in lines that were sometimes bent (we are speaking of a uniform medium), there is no reason why we should not. Or, again, everyone knows that it is only necessary to put a small obstacle in the path of the light from a luminous body to completely shut out our view of it. The light from the setting sun, when the sky is cloudy, is often seen to travel in straight lines.

The images produced by a pin-hole are inverted.—When an object is viewed through a pin-hole camera, it is seen to be upside down upon the screen. Similarly, all images produced by a small aperture are inverted. This inversion is a direct consequence of the fact that light travels in straight lines. That this is really the case can be fully understood by the following simple considerations. Let *H*, in Fig. 110, be the pin-hole, and *AB* the candle. Rays are sent out in all directions by every point of the candle, but of all the rays from a point, such as *A*, only that in the direction *AH* can pass through the hole and form an image *A′*. Similarly, the only ray from *B* which can get through the hole is *BH*, so an image of *B* is formed at *B′*. The same reasoning applies to any part of the candle, hence a complete inverted image is produced.

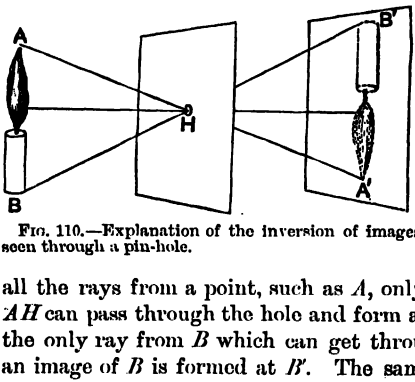

FIG. 110.—Explanation of the inversion of images seen through a pin-hole.

Size of image produced by a pin-hole.—That the size of the image depends upon the distance of the screen from the pin-hole is proved practically by varying the distance of the screen from the pin-hole and measuring the length of the image. The greater the distance of the screen the longer the image. The reason for this alteration in the size of the image is a simple one. The farther the rays of light from the top and bottom of the object travel through the pin-hole, since one is travelling upwards and the other downwards, the farther apart they will be the greater the distance they travel. Consequently, the image is longer the more the screen is moved from the pin-hole.

The relation between the sizes of the object and image according to their distances from the aperture is

$$\frac{\text{Length of object}}{\text{Length of image}} = \frac{\text{Distance of object from aperture}}{\text{Distance of image from aperture}}.$$

The larger the image the less distinct it is, because the small amount of light which can pass through a pin-hole is spread over a greater area.

Illumination due to overlapping of images.—When a pin-hole is made in the front face of a pin-hole camera, an image of the bright object looked at is formed on the screen in the manner described in the preceding paragraphs. If a second hole be pierced, a second image is obtained. When the number of holes is steadily increased, one at a time, the images, it is observed, start overlapping, at the same time becoming blurred. When the number of images has become considerable no separate image can be distinguished, *diffused* light, as it is called, is produced, and the screen is illuminated in the ordinary way.

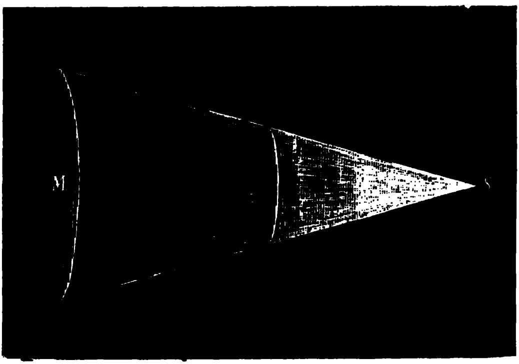

FIG. 111.—To illustrate why the intensity of light diminishes as the distance from it increases.

Intensity of light.—In proceeding from the source of illumination, light spreads out as indicated in Fig. 111, so that though each ray retains its original intensity the number of rays which illuminate a given area depends upon the distance of that area from the luminous source *S*. At twice the distance the rays are spread over four times the area, so their illumin-

ating effect, as at *M*, is only one-fourth of what it is at *m*. The amount of light received from a luminous source is thus inversely proportional to the square of the distance from the source.

42. SHADOWS.

i. Shadows produced by small sources of light.—(*a*) Place a stick vertically between the wall and an ordinary fish-tail gas burner, so that the flat flame and the stick are in the same plane. The shadow of the stick on a screen is sharply defined. Turn the flame through a right angle, so that it is now parallel to the screen. The dark shadow is fringed by another less intensely black.

(*b*) Cast a shadow of a sphere on to a screen, using a small source of light, such as a candle-flame. Notice that the shadow cast on the screen is very distinct, circular, and of equal darkness throughout.

ii. Shadows produced by large sources of light.—(*a*) Substitute a lamp, with a ground glass globe larger than the sphere, for the candle in the last experiment. Notice that the shadow on the screen is made up of two parts, an inner very dark circular patch called the *umbra*, while concentrically arranged round it is a partially illuminated shadow, forming a ring, called the *penumbra* (Fig. 112).

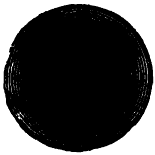

FIG. 112.—Umbra and penumbra of a shadow.

(*b*) Using the lamp with a large globe, as in the last experiment, cast a shadow of a very small sphere. Notice that the shadow comes to a point, as can be shown by moving the screen slowly from the sphere, when the shadow gradually becomes smaller and disappears. This is a *converging* shadow, while those of two previous experiments are *diverging* ones.

Shadow of a rod.—When a thin rod is illuminated by the edge of the flame of an ordinary fish-tail gas burner, the shadow of the rod thrown on a screen has sharp edges, and it is equally black throughout. This, in common with all the phenomena of shadows you have experimentally studied, is the result of the fact that light travels in straight lines. The light from the edge of a flame is in the place of the illuminated pinhole, and the explanation offered for the formation of the image by a small aperture applies here also—except that there is no crossing of the rays and no inversion.

Umbra and penumbra.—When in experimenting with the rod the flame is arranged so as to be parallel with the screen, the dark distant shadow—the umbra—is fringed on each side by a less distinct shadow—the penumbra. Similarly, when a

sphere is illuminated by a small source of light, such as a candle flame, it casts a clearly defined shadow on the screen, or the umbra only is present (Fig. 113). When, however, the source

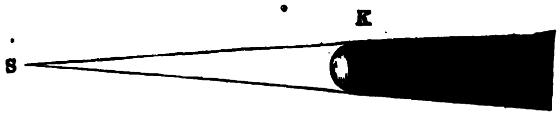

FIG. 113.—When the source of light is relatively small the shadow of an object has no penumbra.

of light is larger, like the ground glass globe of the lamp, the umbra is surrounded by a partially illuminated concentrically arranged shadow—the penumbra. In Fig. 114 *A* represents the illuminated globe, *B* the sphere, and *mn* the screen. By

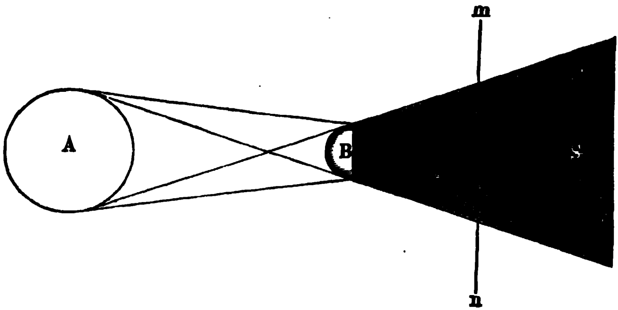

FIG. 114.—Formation of umbra and penumbra of a shadow.

following the course of the rays of light the student will have no difficulty in understanding (1) the formation of umbra and penumbra, (2) how these result from the propagation of light in straight lines.

43. LAWS OF REFLECTION.

i. **Pin method of proving the laws of reflection.**—Fix two slabs of wood at right angles, as in Fig. 115, *AB*, *CD*. Against the upright slab put a piece of glass *EF* with blackened back, so that reflection only takes place from its front surface. Upon the horizontal slab lay a sheet of white paper. Stick a pin *b* in the wood against the glass, and place another pin in the position *a*. Now procure a third pin and stick it into the wood at *c* in such a position

that c, b, and the image of a are in a straight line. Draw with a finely pointed pencil a line along the edge of the glass xy; then take glass and pins away.

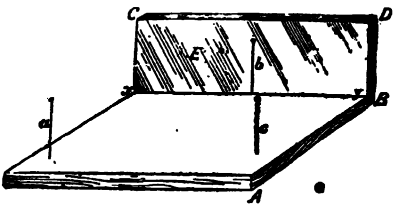

FIG. 115.—Arrangement of pins and mirror for proving the laws of reflection of light.

The paper will be marked by the pin-holes and the line xy. Draw lines through the pin-holes, and at b erect a normal to xy, that is, a line perpendicular to xy. Measure the angles abd, cbd, and compare them (Fig. 116). Repeat the experiment two or three times, with the pins in different positions, and so determine that the angle of incidence and the angle of reflection are equal.

Observe that since the holes made by the pins are all on the same piece of paper with the normal, *the incident ray, the normal, and the reflected ray are all in the same plane.* Moreover, the reflected ray is on the opposite side of the normal from the incident ray.

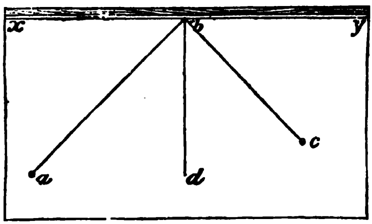

FIG 116.—The angle of reflection cbd is equal to the angle of incidence abd.

ii. **Reflection at two surfaces.**—Place a lighted candle in front of a thick plate-glass mirror, as in Fig. 117. Notice that two images can be seen when viewed a little from one side. One is due to reflection at the front surface, and the other is produced by reflection at the silvered back surface.

iii. **Images formed by plane mirrors.**—(a) Place a knitting needle in front of a plane unsilvered sheet of glass fixed vertically in front of a dark background. Arrange another such needle behind the mirror in such a position that wherever the eye be placed, the needle behind the mirror always appears in the position of the reflected image of the first needle.

It is easy to arrange the needle in the right position behind the mirror, by observing that when this needle apparently moves more in the direction in which the eye is moved than the image does, the needle is too far behind the mirror, and *vice versa.*

Measure the distances of the two needles from the back of the mirror. They should be the same, thus showing that the image is situated as far behind a plane mirror as the object is in front of it.

(b) Arrange two strips of looking-glass about an inch wide, parallel to one another, about two or three inches apart, and at

right angles to a piece of drawing paper pinned on a drawing board. Stick a pin into the paper between the mirrors at a distance of an inch from one mirror. Using pins which are longer than the height of the strips of looking-glass, and adopting the plan described in the last experiment, mark the position the first two or three images of the object appear to occupy. Remove the mirrors, join the positions of the pins with a straight line, and write down what you discover from the experiment.

FIG. 117.—Multiple images produced by reflection at the front and back surfaces of a mirror.

Reflection of light.—When any wave is said to be *reflected*, it is understood that it comes into contact with the surface of some body, and is thrown back from that surface, and travels in a direction opposed to that in which it was originally moving. This may happen in two ways, either *regularly* or *irregularly*. In the first case, it is turned back according to fixed rules, while in the second there is no uniformity about the reflection. The page on which this explanation is printed appears to be white because, owing to the roughness of the paper, of the irregular reflection of the light which falls upon it. Or, if we powder a sheet of glass, the powder seems to be white for a similar reason; there are many surfaces formed from which irregular reflection takes place. The manner in which the rays leave the surface of a body when reflected irregularly can be seen in Fig. 118.

FIG. 118.—Irregular reflection of light.

Laws of reflection of light.—Light is reflected regularly from a plane mirror, that is, a flat reflecting surface. Such a mirror can be made from a variety of substances, but the most common is of bright metal or silvered glass.

The angle at which the light, or any sort of wave, strikes the reflecting surface is called the *angle of incidence*, and the wave an *incident wave.* The angle at which the wave leaves this surface is known as the *angle of reflection*, and the wave as it leaves the *reflected wave.*

There is a definite connection between the angles of incidence and reflection, and it can be expressed as follows:

1. *The line representing the reflected wave is in the same plane with the normal and the line representing the incident wave, and is on the opposite side of the normal from the incident line.*

2. *The angle of incidence is equal to the angle of reflection.*

It has also been learnt by experiment that when a wave strikes a reflecting surface *normally*, *i.e.* having travelled along the normal, it is reflected back upon the same line.

Formation of an image by a plane mirror.—The two rules just enunciated enable the formation of an image by a plane mirror to be easily understood.

Let *MM* be the plane mirror, and *A* a bright spot of light like the head of a pin in Expt. 43. i. First see what happens to the light ray which leaves *A* and strikes the mirror normally. It is reflected back along the same line, and the reflected ray appears to come from a point *A′* along *A A*. In the case of any other rays, such as *AB*, the light ray is reflected in such a way that the angle of reflection *CBD* is equal to the angle of incidence *ABC* and appears to an eye, placed as in Fig. 119, to come along *BD* from a point *A′*, where *BD* produced meets *AA′*. If we make the same construction for any other ray *AB′* it will be reflected and appear to be coming along *B′D′*, which produced backwards

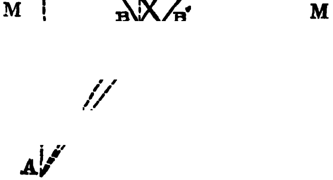

FIG. 119.—Representation of the course of rays producing an image in a plane mirror.

will pass through the same point A'. A' is therefore the image of A, and it can be easily proved by geometry that A' is as far behind the mirror as A is in front of it.

FIG. 120.—Course of rays by which the image of a candle is seen in a plane mirror.

These facts apply equally to the formation of the images of *objects*, which can be considered as accumulations of small material particles to which the construction given above for a point may be applied. For instance, the course of rays by means of which an image of a candle may be seen in a plane mirror is shown in Fig. 120.

CHIEF POINTS OF CHAPTER XI.

Light, like every kind of radiation, is a form of energy. It is a process of transference of energy by ether-waves. Those ether-waves which affect the retina are known as light.

Rectilinear propagation of light.—Light travels in straight lines when propagated through any one medium, but often has its direction changed when passing from one medium to another (see Refraction).

Consequences of rectilinear propagation of light.—(*a*) The images produced by a pin-hole camera are inverted.

(*b*) The size of the image formed by such a camera can be found:

$$\frac{\text{Length of object}}{\text{Length of image}} = \frac{\text{Distance of object from aperture}}{\text{Distance of image from aperture}}.$$

(*c*) Illumination is due to the overlapping of images.

(*d*) The formation of the umbra and penumbra.

Reflection.—Light, in being reflected from suitable surfaces, obeys the following laws:

1. The reflected ray lies in the same plane as the incident ray and

the normal; and is on the opposite side of the normal from the incident ray.

2. The angle of reflection is equal to the angle of incidence.

EXERCISES ON CHAPTER XI.

1. What are the laws of reflection at a plane mirror?

Describe experiments by which you would prove the truth of the laws you give. (1897.)

2. A candle is placed close to a looking-glass, and its reflection in the glass is viewed a little from one side. What will be seen? As far as you can, explain the appearances which you describe. (P.T., 1898.)

3. Describe a pin-hole camera, and explain, illustrating your answer by a diagram, how the image of a luminous object is formed by it.

What experiment would you perform to show why it is that the image first becomes blurred and then disappears when the size of the hole is gradually increased? (1899.)

4. Three candles are placed quite close together in a row at the centre of a room, and a wooden rod is held in a vertical position at a distance of about a foot from the candles. Explain, giving diagrams, why it is that as the rod is moved in a circle round the candles the shadow cast on the walls is in some positions sharp and in others very ill defined. (1899, Day.)

5. The sun shines through a crack in the shutter of a darkened room. A person inside the room says that he sees a ray of light entering the room. Put his statement in a more accurate form. What can he really see? (P.T., 1898.)

6. A small opaque sphere is placed between a gas burner and a white screen, and when the gas is turned down so that the flame is very small it is found that the shadow cast on the screen is quite sharp, but on turning up the gas so that the flame is large, that the edge of the shadow is blurred. Explain the reason for this change, illustrating your answer by means of diagrams. (1898.)

7. State the two laws in accordance with which a ray of light is reflected by a smooth surface, and describe experiments by which you would demonstrate the truth of each of these laws. (London Matric., 1900.)

8. What is an inverted image? If the capital letter F were drawn on paper and held in front of a mirror, how would you have to draw the letter on the paper and how hold the paper, in order that the image of the letter in the mirror should present its ordinary aspect? (London Matric., 1900.)

9. A bright object is placed at a short distance in front of an ordinary looking-glass. An eye looking into the mirror sees, in general, a number of images of the object, the second of the series in order of nearness being usually the most brilliant. Explain this. (London Matric., 1900.)

10. Explain why, if a sheet of paper be placed behind a pin-hole in a thick sheet of cardboard, an image of a brilliantly illuminated object on the other side of the cardboard will be formed on the paper. Why is the image fainter, but more clearly defined, if the pin-hole is very small? (1897.)

CHAPTER XII.

REFRACTION OF LIGHT.

44. REFRACTION AT PLANE SURFACES.

i. **Refraction by water.**—(*a*) Procure a rectangular metal box, such as a cigarette box, and put a wooden or metal scale on the bottom. In a darkened room let sunlight fall slantwise against the edge. The side of the box throws a shadow which reaches, say, to *C*, which, since light travels in straight lines in the same medium, is a continuation of the ray of sunlight *AB*. Without disturbing

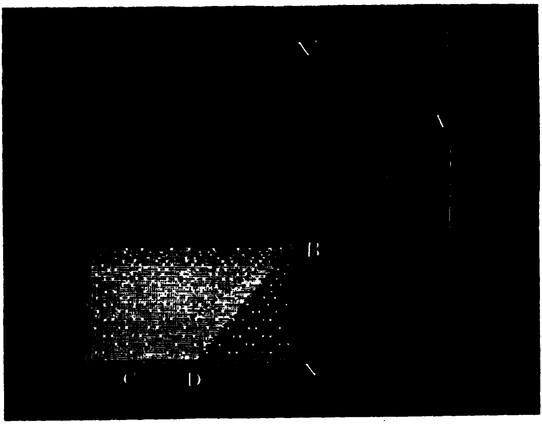

FIG. 121.—Experiment to show refraction of light by water.

anything, fill the box with water. The shadow no longer reaches to *C*, but only as far as *D*. Clearly the light-waves have been bent or *refracted* out of their original course. Notice that *NN'* is the normal, and that the light travelling from the comparatively rare air into the comparatively dense water is refracted towards the normal.

(*b*) Obtain a medicine bottle with flat faces, and paste over one face a piece of paper having a circular hole cut in it (Fig. 122). On the glass draw a vertical and a horizontal line on the clear space as shown. Pour water into the bottle until it reaches the level of the horizontal line. Let a narrow beam of light enter the side of the bottle and strike the surface of the water where the two lines cross; it will be found to be bent in the water towards the vertical line.

FIG. 122.—Bottle for illustrating refraction of light by water.

ii. **Pin method of proving laws of refraction.**—(*a*) Upon a piece of board *ABCD* (Fig. 123) place a sheet of paper, and upon the paper put a piece of fairly thick glass with parallel sides (a thick piece of glass from a box of weights, a paper-weight, or a number of slips of microscope glass will do very well). Rule along the edges of the glass with a finely-pointed pencil. Place two pins, *a*, *b*, as shown in the illustration, and then, *looking through the glass* from the other side, stick in the pins *c*, *d*, so that all four appear in a straight line.

(*b*) Now take away the glass and pins and join the pin-holes on the paper as shown in Fig. 124. Draw the normal *ebf* and the

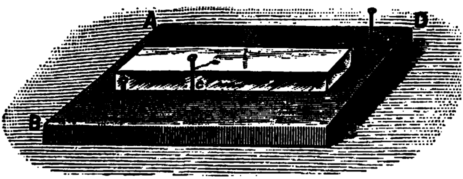

FIG. 123.—Pin method of illustrating refraction of light.

circle *elfg*. Draw *lm* and *gk* perpendicular to *ebf*, and compare the lengths *lm*, *gk*. Obtain the ratio $\frac{lm}{gk}$ for different positions of the pins; it will be found practically the same in all cases in which the same material is used.

Notice that the direction of the ray *cd*, emerging from the glass, is parallel to that of *ab*.

iii. **Phenomena caused by refraction.**—(*a*) Place a bright object, say a coin, on the bottom of an empty basin, and arrange your eye so that the object is *just* hidden by the edge of the basin. Get somebody to pour water into the basin. You will now be able to see the coin without any movement of your eye having taken place. Evidently there has been some bending of the direction of the light rays somewhere.

(*b*) Place a glass cell in front of a white surface brightly illuminated. Let the surface of the water be visible. Put a lump

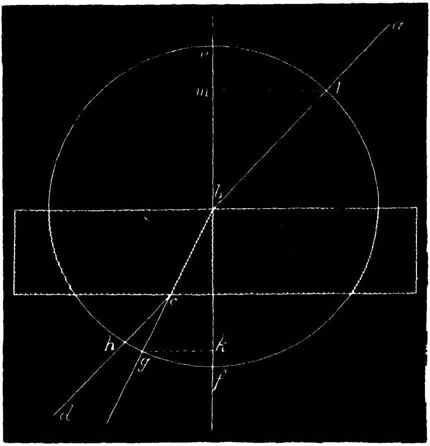

Fig. 124.—Construction for proving the laws of refraction by the pin method.

of ice on the water, and observe the streaky appearance of the illuminated part of the screen. Add syrup, alcohol, and hot water by a pipette. Notice similar effects.

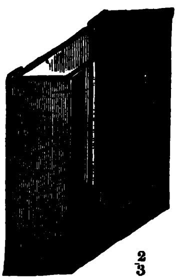

Fig. 125.—Cell with glass sides for refraction experiments.

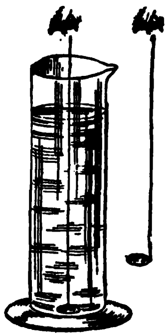

Fig. 126.—Refraction causes the coin to be seen nearer than it really is.

(*c*) Pour the vapour of ether out of a bottle, and observe the appearance on the screen. Examine the shadows of burning gas, a

red-hot poker or of platinum wire through which a current of electricity is passing.

(*d*) Fill a glass cylinder (Fig. 126) with water, and place a coin at the bottom. On looking straight down through the water the coin appears nearer the surface than it really is. Hold another coin near the outside of the cylinder, and place it at such a height that the two coins appear at the same level. The amount by which the coin in the water is apparently elevated by refraction can thus be found. The length of the column of water through which the coin is observed, divided by the distance from the top of the water to the outside coin, gives the index of refraction of water.

(*e*) Repeat the experiment with methylated spirit.

Refraction of light.—Up to the present the light rays have been supposed to be moving through a medium of a uniform density throughout. When this is so, as has been seen, light travels in straight lines, and, if it meets a reflecting surface, it is turned back, according to the laws which have been studied. If, however, the light passes from one medium into another of a different density the propagation of the wave is no longer rectilinear, the passage from one medium into the other is accompanied by a bending of its path. This bending is known as *refraction*, and the ray is said to be *refracted*.

Rules of refraction.—In Fig. 127 the shaded lower part of the diagram represents a denser medium than the unshaded upper portion. The word denser is used here, and in similar connections, to mean optically denser, and must not be confused with what has been said of the density of bodies in Chapter II. Let *RI* represent a ray passing from the rarer to the denser medium, or the ray incident on the surface of the denser medium at *I*. The angle *RI* makes with the normal at *I* is the angle of incidence. The ray is bent; instead of continuing its course in a straight line along *IR'*, it is refracted and travels in the direction of *IS*, which represents the refracted ray, the angle *SIP* being the angle

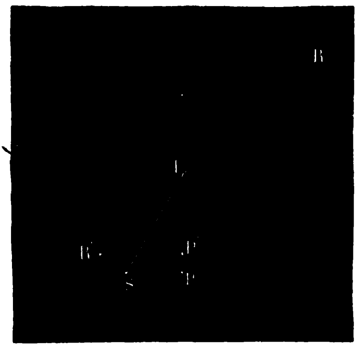

FIG. 127.—Geometrical representation of laws of refraction.

of refraction. The angle $R'IS$, which represents the amount the ray has been turned out of its original path, is called the *angle of deviation*. With the centre I and any convenient radius describe a circle, and from the points where it cuts the incident and refracted rays perpendiculars on to the normal are drawn as in the figure. A perpendicular is also dropped from the point R'. It is clear from geometry that $R'P'$ is equal to the perpendicular let fall on to the normal from the point where the incident ray cuts the circle. The ratio between the lengths of $R'P'$ and SP is constant for the same two media, *e.g.* air and water, whatever the angle of incidence. This ratio is called the *index of refraction*. Its value for air and water is about $\frac{4}{3}$; for air and glass roughly $\frac{3}{2}$, depending upon the kind of glass.

The laws of refraction are then:

1. *The incident ray, the normal, and the refracted ray are all in the same plane. The incident and refracted rays are on opposite sides of the normal.*

2. *If a circle be described about the point of incidence, and perpendiculars be dropped upon the normal from the intersections of this circle with the incident and refracted rays, the ratio of the lengths of these perpendiculars is constant for any two given media.*

Refraction through a plate with parallel sides.—In the case of a ray of light passing completely through a plate of glass, having its sides parallel, the ray is bent towards the normal when entering the glass, and away from the normal when emerging, so that its course is as shown in Fig. 128. The ray is thus displaced laterally, but it emerges in a direction parallel to its original direction. In constructing a diagram for any similar case, it should be borne in mind that when a ray passes from a less dense to a more dense medium, it is bent towards the perpendicular to the separating surface, and when a ray passes from a dense to a rarer

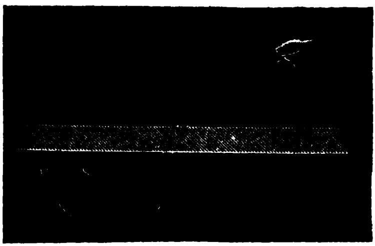

FIG. 128.—Refraction causes the object S to be seen at S'.

medium it is bent away from the perpendicular to the separating surface.

Various effects of refraction.—The common experiment with a coin at the bottom of a basin, where, being first hidden from view by the edge of the basin, it becomes visible again when water is poured into the basin, is easily explained by tracing out the path of the light.

In Fig. 129 let *c* be the position of the coin, in which it is just hidden as far as the eye is concerned by the edge of the empty basin. If the rays from the coin *c* be continued in straight lines these lines will evidently pass above the eye. Now when the water is put in, these rays, which before miss the eye, are

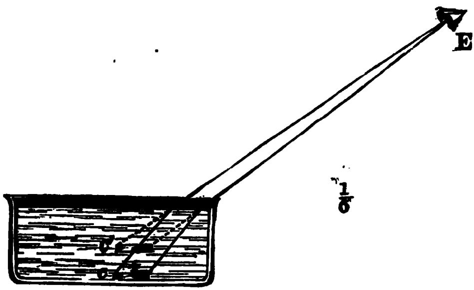

FIG. 129.—When the trough is empty the coin *c* is invisible to an eye at *E*, but when it is full of water the coin is seen at *c*.

refracted in passing out of the water and just enter the eye, making the coin appear to be in the position *c′*. The right side of the vessel, if continued upwards, represents the normal, and evidently in passing out of water into air the light-waves are bent away from the normal.

The same kind of construction applies to the case when an object is seen obliquely through a thick glass plate (Fig. 128). The object is displaced and also made to appear nearer than it really is.

The streaky appearance seen when the light from a lantern is passed through water containing ice is due to the repeated refraction of the light on passing into layers of water of different densities (Expt. 44. iii.). This reason, too, explains the results obtained when alcohol or syrup are mixed with water.

The refraction of light in its passage from one medium

into another of different density explains several other very familiar observations. A stick held in anything other than a perpendicular position in water appears to be bent upwards (Fig. 130). If a straight stick is fixed upright in water and looked at from a point a few feet above the end, it will appear shorter than it really is, in the proportion of three to four, so that if a length of four feet is under water, it appears to be only three feet long. In the same way standing bodies of water always appear shallower than they really are on account of refraction. A pool of clear water when viewed from a point vertically above the surface only appears $\frac{3}{4}$ of its actual depth.

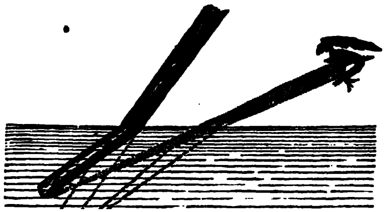

FIG 130.—Refraction causes the stick to appear bent instead of straight.

45. REFRACTION THROUGH A PRISM AND LENS.

i. **Pin method of tracing deviation by a prism.**—Stand a prism upright, that is, upon one of its ends, upon a piece of white paper. Stick two pins into the paper in the positions D, E (Fig. 133), place two more E', D', on the opposite side of the prism, so that the four appear in a straight line when looking through the prism. Draw the outline of the prism *abc*, and then take away the prism and the pins and connect the pin-holes as shown in the diagram. It will be found that the ray is bent towards the base of the prism both when it enters and emerges.

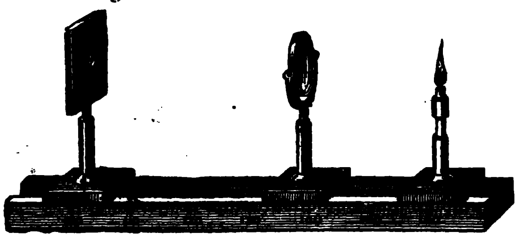

FIG. 131.—Inverted image produced by convex lens.

ii. **Refraction by a lens.**—Obtain a convex lens, that is, a lens thicker at the middle than at the edges, and notice that if it is held

between a luminous object and a small screen, an inverted picture of the object will appear upon the screen.

iii. **Formation of images by lenses.**—(*a*) Place a convex lens between a lighted candle and a screen, as in Fig. 131, and observe that an inverted image of the candle appears upon the screen.

(*b*) Fix a convex lens of long focal length to form a real image of any object, as *e.g.* a window, on a card placed at the position shown in Fig. 132, in which *AB* represents the object. Next place on the other side of the card a convex lens of short focal length in such a

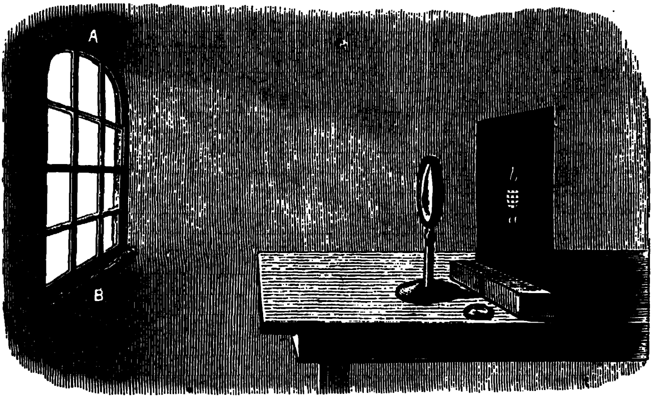

FIG. 132.—Formation of image by a lens.

position that when looking through it any mark upon the card is clearly seen magnified. If the card is now taken away, the image formed by the other lens is seen magnified. Such an arrangement of lenses forms the ordinary astronomical telescope.

Refraction through a prism.—When a wedge-shaped piece of glass, or a prism, as it is called in optics, is interposed in the path of a ray of light from a small hole in the cap of a lantern, it is easy to see by watching the image of the hole on a screen that the image moves in a direction towards the base of the prism. This is because the ray is bent by its passage through the prism, so that on its emergence from the glass it continues in a new path inclined towards the base of the prism. The amount of bending experienced by the ray of light depends upon (1) the angle between the inclined sides of the prism meeting in its edge, or the angle of the prism, as it is called; (2) the material of which the prism is made, and (3) the nature of the incident light.

If two prisms of the same angle and material are so arranged that the edge of one adjoins the base of the other, the second prism undoes the bending of the first, and the ray as it leaves the combination of prisms continues its path in a direction parallel to the incident ray, though not, of course, in the same straight line with it.

Path of a ray of light through a prism.—In Fig. 133 let the triangle *abc* represent a section of the prism at right angles to its faces, such as we should see by looking at the end of it. Suppose *DE* is a ray of light striking the face *ab* of the prism. The light on entering the prism passes from the air into the glass, or *from a rarer into a denser medium*, and is bent *towards* a line drawn perpendicular to the face of the prism at the point where the ray of light strikes it. It consequently travels along the line *EE′* until it reaches the face *ac* of the prism. Here it passes from the glass into the air, *i.e. from a denser into a rarer medium*, and is, in such circumstances, bent *from* the perpendicular, and travels along the line *E′D′*. In every such passage through a prism it is noticed that the light is always bent or refracted towards the thick part of the prism.

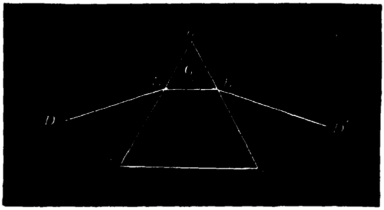

FIG. 133.—Construction to show the path of a ray of light through a prism.

Refraction through a lens.—Most lenses are of glass with curved surfaces, which are portions of spheres. In some lenses, however, one surface is quite plain. All lenses can be divided into two classes—*convex* or *converging*, and *concave* or *diverging*. Converging lenses are thicker in the middle than at the edges, and have the power of forming real images of objects. Concave lenses are thinner in the middle than at the edges, and are unable to form real images of objects.

To understand the action of the lenses upon the course of rays of light through them, it is simplest to regard them as being built up of parts of prisms in contact, as shown in Fig. 134, where a convex lens is built up in this way. A ray of light falling upon any one of these prisms is refracted towards its thicker part, and consequently they all converge towards

a point, which, if the incident rays are parallel, is known as the *principal focus* of the lens, as *F* in Figs. 134, 135. To actually find the distance of the principal focus away from the centre

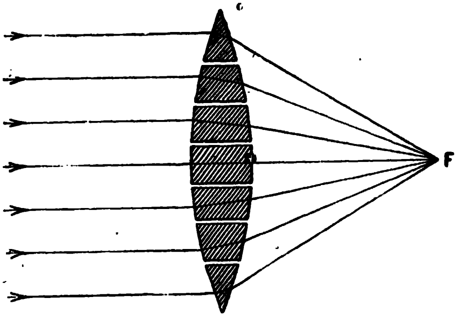

FIG. 134.—To explain the refraction of light by a convex lens.

of the lens, that is, its *focal length*, it is only necessary to form an image of the sun by it on a screen and to measure the distance between the lens and the screen.

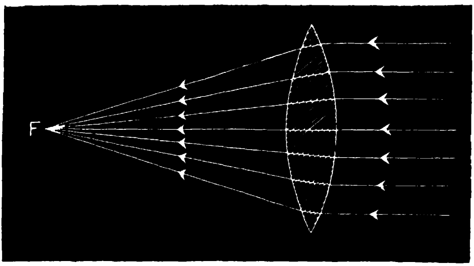

FIG. 135.—Parallel rays falling upon a convex lens are brought to a focus at one point *F*, known as the principal focus.

The telescope.—The principle of the refracting astronomical telescope can now be explained. Let *O* (Fig. 136) be a double convex lens forming an image *ba* of the object *AB*. This image becomes the object to a second smaller, though in other respects similar, lens placed near the eye. The second lens forms an enlarged image *B′A′* of this first image *ba*, in the way shown in the figure. A lens placed in the same relation to

the smaller one, as *O* is in the figure, is called the *object* glass, while the smaller one which magnifies the image formed by the

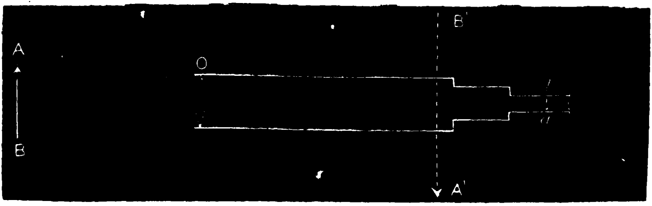

FIG. 186.—Principle of construction of a simple telescope.

first constitutes the *eye-piece.* In an opera glass, or toy telescope, the small lens is usually a double concave lens.

CHIEF POINTS OF CHAPTER XII.

Refraction of light.—A ray of light passing from a less dense to a more dense medium is bent towards the perpendicular to the separating surface, and conversely. The laws of refraction can be stated thus;

1. The incident ray, the normal, and the refracted ray are all in the same plane. The incident and refracted rays are on opposite sides of the normal.

2. If a circle be described about the point of incidence and perpendiculars be dropped upon the normal, from the intersections of this circle with the incident and refracted rays, the ratio of the lengths of these perpendiculars is constant for any two given media.

Refraction by a prism.—The deviation of a beam of light caused by the action of a prism depends upon (*a*) the angle of the prism, (*b*) its material, (*c*) the nature of the light.

Refraction through a lens.—Most lenses are of glass with curved surfaces, which are portions of spheres. They can be divided into convex or converging, and concave or diverging lenses. The point to which parallel rays after refraction converge, or appear to diverge, is called the *principal focus*.

EXERCISES ON CHAPTER XII.

1. A bright bead is placed at the bottom of a basin of water, and a person stands in such a position that he can just see it over the edge of the basin. While he is looking, the water is drawn off. How will this affect his view?

Draw a diagram showing the direction of a ray of light passing from the bead through the water and the air in each case. (P.T., 1897.)

2. A thick layer of transparent liquid floats on the surface of water. Trace the course of a ray of light from an object immersed in the water through the floating liquid to the air. (1897.)

3. Describe an experiment to show the path of a ray of light which passes obliquely through a thick plate of glass. Illustrate your answer by a sketch in which you indicate clearly the path of the ray in the air before it enters the glass, in the glass, and in the air beyond the glass. (1898.)

4. An upright post is fixed in the bottom of a pond which is three feet deep; the top of the post is three feet above the water. How will the post appear to an eye about the level of the top of the post and four or five feet away from it?

Draw a figure to illustrate your answer.

What will be seen as the eye moves further and further back from the post? (P.T., 1898.)

5. Describe in detail, giving a sketch of the apparatus, an experiment to show that when a ray of light passes from water to air it is bent away from the perpendicular or normal. (1899, Day.)

6. State the laws of the deviation of light when passing from any medium to one of different optical density. (London Matric., 1899.)

7. A boy wades in a pond which everywhere reaches to about the level of his knees. On account of the water, some of the pebbles with which the bottom is covered are invisible and others are not seen in their true places. Explain this, and illustrate your answer by a diagram. (Queen's Sch., 1899.)

CHAPTER XIII.

ANALYSIS OF LIGHT. COLOUR.

46. DISPERSION.

i. **Dispersion by a prism.**—In a piece of card cut a slit about 2 cm. long and 1 mm. wide. Place the card, with the slit vertical, in front of a fish-tail gas flame. Arrange a prism on a stand, so that it is of the same height as the slit, and has its refracting edge vertical. Put the prism a *short distance from the slit*, and look into it so as to see the image of the slit. Observe that the light is refracted towards the base of the prism, and that it is decomposed into constituent colours, which are differently bent by the prism. The violet light is refracted most and the red light least. Colours between these limits are bent by intermediate amounts. Name the colours you can see.

The band of colour is called a *spectrum*; the light is said to be *dispersed* by the prism.

ii. **Dispersion a consequence of unequal refraction.**—(*a*) Place a red glass against the slit and notice that only a red image of the slit is visible. Without moving your eyes substitute a blue glass for the red one. A blue image is seen, but not in the same position as the red one; it is bent more away from the refracting edge of the prism.

FIG. 137.—A hollow prism for holding liquids to show the decomposition of light by unequal refraction.

(*b*) Place a second prism with its base in the same direction as that of the first. Notice a longer band of colour than in 46. i. is obtained, but it is fainter. The amount of dispersion has been increased.

(*c*) Place the second prism so that its base adjoins the apex of the first prism (Fig. 139). The band of colour disappears.

(*d*) Substitute a hollow glass prism (Fig. 137) filled with carbon bi-sulphide for the solid glass prism used in the preceding experiments. Observe the increased length of the spectrum, owing to the greater dispersive power of the carbon bi-sulphide.

Refraction is accompanied by dispersion.—In all the cases of refraction which have hitherto been considered, the phenomena have been described as if all the ether-waves, which are contained in white sunlight, are bent equally, but this is really not so. What is commonly called "red" light is not so much bent out of its path by a prism as "blue" light. Or, expressing the same fact in another way, red light is less *refrangible* than the blue light. It is found by accurate experiments, which the student will find described in books on light, that the sensation of red upon the retina is due to the absorption of ether-waves which are long and slow compared with those waves which when absorbed by the retina give rise to the sensation of blue. The shortest, most rapid waves are bent most; the slowest, longest waves are bent least. The shortest, most rapid waves which affect the retina give rise to the sensation of violet. Since a prism bends ether-waves of different lengths unequally in this way, it provides a means of separating waves of different lengths from one another. Because they are bent differently the ether-waves are separated or *dispersed* by the prism. This may be expressed by saying that a prism can analyse light composed of waves of different lengths.

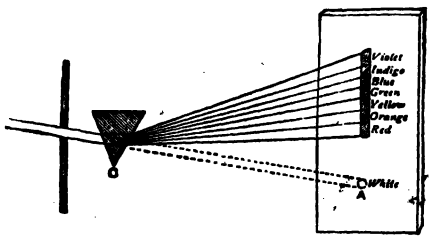

FIG. 188.—To illustrate the decomposition of white light by a prism.

Analysis of light by a prism.—When sunlight, or, as it is called, white light, is passed through a prism, it is decomposed or dispersed owing to the different refrangibility of the various kinds of light contained in it. An examination of the band of colour or *spectrum* will show that one colour shades imperceptibly into the next. There is, then, an infinite number of waves of different lengths comprised in the white light from the sun, and each ray is bent to an extent depending on its wave-length.

If the decomposed sunlight, instead of being collected on a screen, be passed through a second prism similarly arranged, it will be seen that the band is longer, or the dispersion is greater. The amount of dispersion also depends upon the material of which the prism is made. Glass produces a much greater amount of dispersion than water; flint-glass possesses twice the dispersive power of crown glass; carbon bisulphide, again, has even more dispersive power than flint-glass.

Although a continuous band of colour is observed when sunlight, or limelight, or a gas- or candle-flame is seen through a prism, this continuous spectrum is not always produced. For when substances such as sodium, strontium, and lithium, or their compounds, are burnt in a non-luminous flame, and observed through a prism, a spectrum consisting of bright lines, which are different for different substances, is seen. A prism may thus be used, and is used, to analyse light. The light of incandescent sodium vapour, produced by burning common salt in a flame, when observed through a prism is characterised by a yellow line, and the light emitted by other substances when burning are each distinguished by rays of a particular colour and position in the spectrum.

47. RECOMPOSITION OF WHITE LIGHT.

i. Recomposition of light by a second prism.—Place a prism in front of an illuminated slit, as in Expt. 46. i. Observe the band of colour, or spectrum. Place a second prism against the first one,

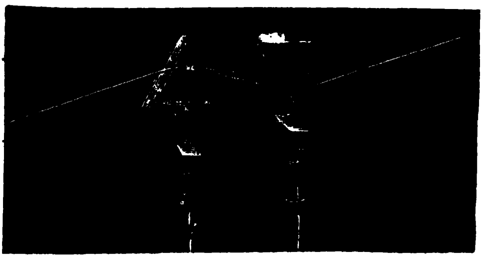

FIG. 139.—Recomposition of light by a second prism.

but with the refracting edge adjacent to the base (Fig. 139). This prism undoes the work of the first one; and no spectrum can now be seen, but only the illuminated slit.

ii. **Recomposition by colour disc.**—Upon a round piece of card paint sectors of the different colours contained in the spectrum, arranging the areas of the coloured sectors as nearly as possible in the proportion in which they occur in the spectrum.

Place the card upon a whirling table (Fig. 140) or upon a top, and rotate it rapidly, when it will be found that light from the card gives rise to the sensation of white or grey.

Formation of white light from its constituents.—Just as it is possible to analyse white light, splitting it up into its constituent colours or wave-lengths, so, by suitable arrangements, these separated or dispersed colours can be made to recombine, forming white light over again. This building up, or synthesis, of white light can be effected in the following ways :

1. By interposing a second prism with its angle reversed. The dispersion of the first prism is neutralised, and the beam of light leaves the second prism in a direction parallel to the beam incident upon the first prism.

2. By causing the dispersed constituents to fall upon a double convex lens. A screen placed at the focus of the lens shows a white image of the slit.

3. By the colour disc.

The colour disc.—The explanation of the recombination of the separate colours of the spectrum by means of a rapidly revolving disc, as in Experiment 47. ii., is very simple. It is due to what is called the *persistence of images* on the retina of the eye. Each impression the retina receives lasts for a certain length of time—a fraction of a second. It is not an instantaneous impression only. Think of the common trick of whirling round a stick with a spark on the end—you know this gives rise to the impression of a continuous circle of light. This is because the second impression of the spark is received by the eye before the first impression has died away. Similarly, the impression of one sector, say, a red one, has not disappeared

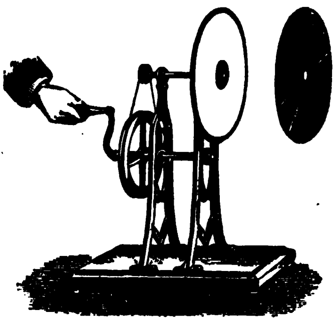

FIG. 140.—Rotating disc, to show the recom[illegible] white

before the next is received, and while these compounded impressions linger a third one comes along. The blurred total of all these rapidly occurring impressions produces the greyish white tinge seen when a colour disc is whirled.

48. COLOUR.

i. **Colour of transparent bodies.**—(*a*) Introduce pieces of coloured glass in succession between a prism and a slit illuminated by the flame of a fish-tail burner and observe the effects produced. Carefully record your observations.

The coloured glasses *absorb* certain constituents of white light. Thus, a blue glass absorbs all the colours except the blue, indigo, and violet. A red glass similarly absorbs all the light except the red and perhaps some of the orange.

(*b*) Place a piece of dark green glass and a piece of ruby red glass together between the slit and the light. All the colours are absorbed, and nothing is seen on looking through the prism.

(*c*) Take a piece of ruby red glass and a piece of dark green glass. Why do they appear red and green?

What coloured light passes through the green glass? Look at some red, yellow, blue, green, etc., objects through this, and explain why they appear of the colours you see. Do the same with the red glass.

(*d*) Take the two glasses in a dark room with two candles. Place a screen upright, and in front of it place a candle and the red glass. What colour does the screen appear?

Do the same with the green glass, and then place both glasses alongside with a candle behind each, so that the screen is illuminated by light through each. What colour does it appear, and why?

ii. **Colour of opaque bodies.**—(*a*) Paint sheets of cardboard with various brilliant colours. Send the light from a lamp in an otherwise dark room upon them and catch the reflected light on white sheets of cardboard. Notice that the colour of the light reflected is the same as that of the surface from which it is reflected.

Colour of transparent bodies.—*The colour of transparent bodies is due to the constituents of white light transmitted by them.* A blue solution through which the light from a lantern is passed is blue because, of all the colours of the spectrum, it is able to transmit easily only the blue rays; the others, green, yellow, orange, red, etc., are absorbed by the coloured solution. Consequently, if this transmitted blue light falls upon a sheet of red glass it is, in its turn, absorbed; red glass only transmits red light, that is why it is red. So that a combination of the blue solution and a piece of red glass is quite opaque to light—none of the colours of the spectrum can pass. Similarly, pieces of red and blue glass together are, if thick enough, quite opaque. If a strip of coloured glass, or a solution in a narrow

test-tube, is held between a spectrum and a screen, it appears as a black shadow upon the screen in all parts of the spectrum except at the colour which it is able to transmit. Colourless transparent bodies like glass, water, and so on, transmit all the colours of the spectrum with equal facility.

Colour of opaque bodies.—*The colour of opaque bodies is due to the constituents of white light which they reflect.*—If the light from a lantern in an otherwise dark room be made to fall upon sheets of cardboard which have been painted with various brilliant colours, and the light reflected from the coloured sheets be caught on a white surface, it is at once seen that the colour of the light reflected is the same as that of the card from which it comes.

Coloured opaque bodies when passed through a continuous spectrum only appear coloured when in that colour of the spectrum which is the colour they appear to have in white light. A red substance like sealing-wax is red only when there are red rays falling upon it which it can reflect. The sealing-wax absorbs all the other constituents of white light; and hence if it is held in blue light, or light of any other colour than red, since all the light rays of this colour are absorbed, no light is reflected and it appears black. A white opaque substance, like a sheet of paper, appears white because it reflects all the constituents of white light equally well. Similarly, if a card painted violet is passed through a spectrum it only appears violet when in the violet rays, and in all other colours it seems black, because it cannot reflect these colours.

General considerations.—In every case the colour of a body depends on selective absorption or selective transmission. Of the coloured rays of white light one portion is absorbed at the surface of the body. If the unabsorbed portion traverses the body it is coloured and transparent; if, on the contrary, it is reflected the body is coloured and opaque. In both cases the colour depends upon the constituents of white light which are left to reach the eye after the other constituents have been absorbed. Bodies which reflect or transmit all colours in the proportion in which they exist in the spectrum are white; those which reflect or transmit none are black. Between these extreme limits infinite tints exist depending on the smaller or greater extent to which bodies reflect or transmit some colours and reflect others.

Referring again to the blue glass (p. 183), it absorbs preferably the red and yellow rays of white light, transmits the blue rays almost completely, the green and violet less so, and hence the light seen through it is blue.

Bodies have no colour of their own; the colour of a body changes with the light which falls upon it. It is interesting to remember that this absorption of certain constituents of light necessitates a using up of energy. But since energy cannot be destroyed it is in these cases converted into heat. Theoretically, a blue glass would get hotter than a red one, because the former absorbs all the red rays, and these have a greater heating effect than blue rays.

CHIEF POINTS OF CHAPTER XIII.

Analysis of light by a prism.—The points to be remembered in connection with this are:

1. That if a beam of monochromatic light, that is, light of one wave length, traverses a prism, it is bent out of its original direction, but the amount of bending produced by any particular prism depends upon the colour of the beam of light used, being greatest for violet and least for red light.

2. That if light from any source passes through a prism, it is broken up or analysed into its different components, each ray of elementary colour that enters into the composition of the light being bent by a different amount.

3. That if a beam of white light from a slit pass through a prism, it emerges as a coloured strip termed a *spectrum*, in which the colours red, orange, yellow, green, blue, indigo, violet, may be recognised.

White light can, therefore, like a chemical compound, be broken up into simpler elements.

Recomposition of light—the colour disc.—The analysis of white light is noted above; the synthesis, or recomposition, can be effected:

1. By making the coloured band or spectrum, produced when light has passed through one prism, traverse a second prism having its refracting angle reversed.

2. By rotating a disc of cardboard painted in segments of violet, blue, green, yellow, orange, and red.

Colour of transparent bodies.—The colour of transparent bodies is due to the constituents of white light *transmitted* by them.

Colour of opaque bodies.—The colour of opaque bodies is due to the constituents of white light which they *reflect*.

EXERCISES ON CHAPTER XIII.

1. Describe and explain the effects observed when cards coloured bright red, green, and blue respectively, are passed from the red to the blue end of the spectrum. (1897.)

2. A ray of white light is passed through a glass prism; make a sketch showing how the direction of the ray is changed by its passage through the prism and the order of the colours seen when the light falls on a screen.

How would you show that when these colours are re-combined white light is produced? (1898.)

3. Describe an arrangement by means of which a spectrum may be formed upon a screen.

If the light is made to fall upon a piece of red glass before reaching the screen, how and why will the spectrum be affected? What would the effect have been if blue glass had been used? (1897.)

4. How can it be proved that:

(*a*) White light is a mixture of many colours? (*b*) Different colours have different degrees of refrangibility? (P.T., 1897.)

5. A room is lighted by one small window, which can be completely covered by a screen of dark red glass, or by one of blue glass, or by both put together. In the room is a stick of red sealing-wax, a piece of blue ribbon and a lily. What colour does each of these things appear when (*a*) the red screen covers the window? (*b*) the blue screen covers the window? (*c*) when both screens cover the window? (P.T., 1897.)

6. What is meant by the *dispersion of light*? On what fact does it depend?

7. Explain the term *refrangibility* as applied to a ray of light. Are rays of all colours equally refrangible?

8. It is sometimes said that "red glass colours the sunlight red," and that "blue glass colours the sunlight blue." Mention facts or experiments which show that this is not accurate. Put the statement in a more accurate form. (P.T., 1898.)

9. An extended spectrum is thrown on a black screen, and a card, on which the letters *W*, *R*, *V* have been painted in white, red, and violet respectively on a black ground, is held in succession so as to be illuminated by the different parts of the spectrum. Describe and explain the appearance of the letters in the different parts of the spectrum. (1899.)

10. Some glass houses in which ferns are grown are constructed of green glass. Describe the appearance, to an observer in such a house, of a lady in a red costume carrying a book with a bright blue cover. Give reasons for your answer.

11. How would you explain the effect of a stained glass window upon sunlight to a class of children? What simple experiments would you perform to convince them of the truth of your statements?

12. Why does a field poppy appear red? Describe how you would arrange an experiment to make it appear black.

13. Describe exactly what happens to the direction and quality of he light when a narrow beam of parallel white light falls upon one face of a three-cornered prism, held in such a way that the light emerges through an adjacent face of the prism. What would you see if this beam of light, after thus passing through the prism, is received upon a sheet of white cardboard? What difference would it make if the beam of light before entering the prism is passed through a sheet of red glass? (London Matric., 1899.)

CHAPTER XIV.

TERRESTRIAL MAGNETISM.

49. NATURAL AND ARTIFICIAL MAGNETS.

i. **Attractive property of lodestone.**—Examine a piece of lodestone. Dip it into iron filings. Observe that the filings adhere in tufts to certain parts of the lodestone.

ii. **Directive property of lodestone.**—Take a second piece of lodestone which has been roughly shaped so that the places where the filings adhere are situated near its ends. Support the piece of lodestone in a wire stirrup as shown in Fig. 141, and prove that even if at first arranged in any other way, the piece of lodestone, after swinging about for some time, eventually comes to rest along a certain line, and one end of the lodestone, which you can mark with chalk, always points in the same direction.

FIG. 141.—A lodestone attracts iron filings, and, if free to turn, sets itself in a definite direction.

iii. **Action between two lodestones.**—Leave the piece of lodestone of the last exercise suspended in its position of rest. Bring up the first piece of lodestone towards it in such a manner that one of the places where the filings adhered points at the end of the suspended piece. Observe what happens. Now point it at the other end of the suspended lodestone and again observe the result. In one case attraction takes place, while in the other repulsion ensues.

iv. **Magnetisation by means of lodestone.**—Take a good sized sewing needle and fix it on the table with a little soft wax. Using the piece of lodestone from the stirrup in the last experiment, and

beginning at the point of the needle, rub the end of the lodestone along the length of the needle, and when you get to the eye, raise the lodestone and bring it again on to the point of the needle and repeat the stroking process. Do this about ten or twelve times.

v. **Properties of a magnet.**—Examine the needle which has been rubbed with the lodestone. No change of appearance can be seen, but it will now attract iron filings at its ends. Support it in a tiny stirrup (Fig. 142), and see that it arranges itself as the shaped piece of lodestone did. Also notice that while the point is either attracted or repelled by the end of the shaped lodestone, the eye is repelled or attracted, that is behaves in an exactly opposite manner.

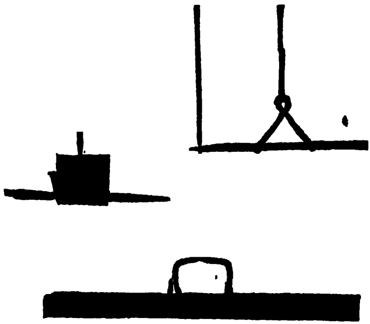

FIG. 142.—Convenient methods of suspending magnets to illustrate their directive properties.

The needle has been made into a magnet, or has become magnetised. Most filings are attracted at its ends, which are in consequence termed the *poles* of the magnet.

vi. **Artificial magnets.**—Examine several forms of artificial magnets. Notice that some are in the shape of bars, others in that of a horse-shoe.

Treat the bar magnet in the same way as the shaped lodestone, thus: (*a*) Support in a stirrup, and see that it arranges itself along the same line (Fig. 143).

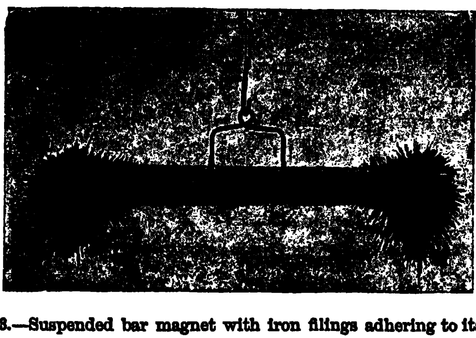

FIG. 143.—Suspended bar magnet with iron filings adhering to its poles.

(*b*) Dip both ends successively into iron filings. Notice and sketch the way in which the filings form a tuft. These ends are the poles. No filings adhere to the centre of the magnet.

(c) Support the magnetised needle as in Expt. 49. v. Bring first one end of the bar magnet, and then the other, up to the point of the needle. Notice and record the result. Repeat, using the eye of the needle.

Lodestone.—Lodestone is a chemical compound of iron and oxygen (p. 216) which occurs in the earth's crust. It is more commonly known as *magnetite* (p. 216). The name lodestone is reserved for those varieties which have magnetic properties; the name itself means "leading stone" and refers to its early use for navigating ships. This mineral is found in considerable quantities in Scandinavia, Asia Minor, United States, and other countries.

Artificial magnets.—The experiments already described teach several important facts. Lodestone is naturally able to attract iron-filings. It arranges itself in a particular way when allowed to hang freely. It can impart these properties to pieces of steel, converting them into artificial magnets. These, in their turn, can make other pieces of steel into artificial magnets. All artificial magnets arrange themselves in the same way when freely suspended. *In every respect an artificial magnet has the same magnetic properties as lodestone.*

50. PRIMARY LAWS OF MAGNETISM.

i. **Magnetic attraction and repulsion.**—(a) Substituting the bar magnet for the shaped lodestone, magnetise another needle as in Experiment 49. iv.

(b) Support the two magnetised needles, which you now have, each in a little stirrup. Allow them to swing freely and come to rest. On the ends of the two needles which point in the same direction stick a piece of paper, or mark them in some other convenient way.

(c) Leave one needle in its stirrup and take the other out. Holding the needle in your hand, bring the marked end up to the marked end of the suspended needle. Notice repulsion. Bring the unmarked end of the needle in your hand up to the unmarked end of the suspended needle. Again notice repulsion.

(d) Now bring the unmarked end of one against the marked end of the other. Notice attraction.

(e) Substitute a soft-iron nail for the needle in your hand in the last experiment. Notice that when either end of the nail is brought up to the marked or unmarked end of the suspended magnetised needle, attraction ensues.

Since unmagnetised iron will attract both poles of a magnetic needle, we are led to an important conclusion, viz., that *repulsion is the only sure test of permanent magnetisation.*

ii. **Action between poles of magnet and compass needle.**—(*a*) Procure an ordinary compass needle, which is simply a light magnetic needle supported as in Fig. 144, so that it can move easily in a horizontal plane. Notice that one end, which is marked, always points towards the north, and is called the *north-seeking* end. Bring up towards this marked end of the compass needle that end of a bar-magnet which points to the north, when it is freely suspended in a stirrup, and which is marked with an *N*. Notice that they *repel* one another. Repeat the experiment using the unmarked, or *south-seeking*, end of the needle and bar-magnet. Observe they similarly *repel* one another.

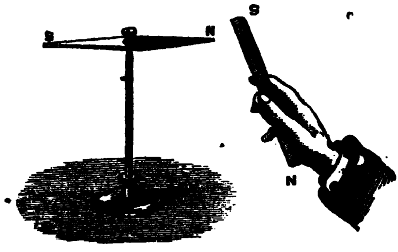

FIG. 144.—Common form of compass needle and stand.

(*b*) Repeat the last experiment, only make the unmarked end of the bar-magnet approach the marked end of the needle. Observe that they rush together or *attract* one another. Similarly, notice that unlike poles in all circumstances attract one another.

iii. Place a bar-magnet upon the table. Arrange a compass needle upon it so that its point of suspension is on the neutral line of the magnet. Set the compass needle swinging and then allow it to come to rest. Observe that the needle arranges itself, with its marked end pointing towards the unmarked end of the magnet. The reverse is true of the other pole of the needle (Fig. 145).

FIG. 145.—Unlike poles attract one another.

We say the magnet exerts a *directive* force upon the needle. Put the needle in other positions on the magnet and notice the same fact.

iv. **Result of breaking a magnet.**—(*a*) Magnetise a piece of clock-spring. Find which end is repelled by the marked end of a suspended magnetic needle, and stick a piece of paper on this end. Convince yourself that the other end of the piece of hardened spring is attracted by the marked end of the suspended needle. Observe, too, that the middle of the piece of spring has no effect on the needle.

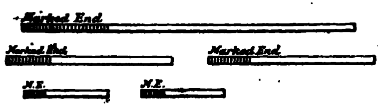

FIG. 146.—Breaking a magnet does not isolate the two poles.

(*b*) Break the piece of spring into halves, and examine each piece by bringing the ends of the pieces in turn up to the suspended needle. What was, before breaking, the middle part of the piece of spring is

now found to affect the needle and to attract the iron filings. Or, each piece is a perfect magnet.

(c) By means of the suspended magnetised needle satisfy yourself that the other end of the half, which is marked, is attracted by the

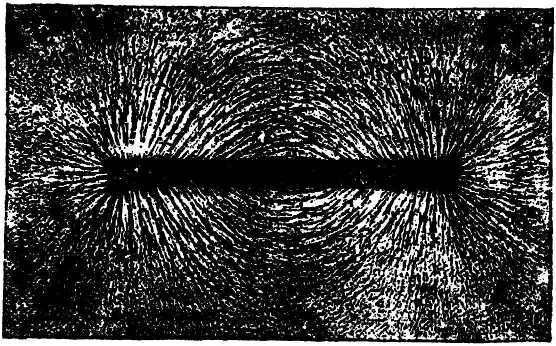

FIG. 147.—Arrangement of iron filings sprinkled near a magnet to show the directions of the lines of magnetic force.

marked end of the needle, and that the other end of the half, which is unmarked, repels the marked end of the needle.

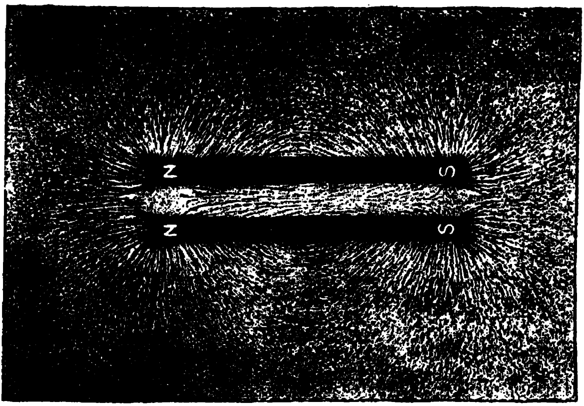

FIG. 148.—Arrangement of iron filings sprinkled near two magnets with like poles adjacent to one another.

(d) Break one half into two equal parts. Show in the way used

in the last experiment that each part is a perfect magnet. **Also find how the poles are arranged. Record your results, and compare them with Fig. 146.**

(*e*) Very nearly fill a small narrow test-tube with *steel* (not iron) filings, and close the tube with a well-fitting cork. By the method already learnt, and using a large, strong magnet, magnetise the tube and its contents as if it were a bar of iron. Satisfy yourself that you have magnetised it by observing its action on a magnetic needle. Now shake the filings out of the tube on to a sheet of paper; toss them about, and then replace them in the tube, and again test its magnetic condition with a magnetic needle. The tube and its contents no longer behave as a magnet.

v. **Lines of force.**—(*a*) Place a bar magnet on the table, and over it place a thin sheet of cardboard. Sprinkle fine iron filings on to the card, either from a fine pepper castor or from a fine muslin bag.

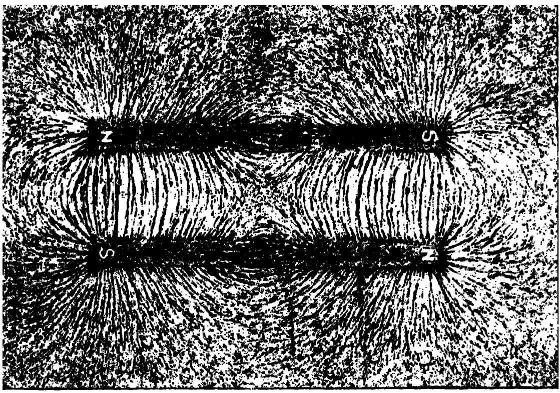

FIG. 149.—Arrangement of iron filings sprinkled near two magnets with unlike pole adjacent.

Gently tap the sheet of cardboard, when the filings will be seen to arrange themselves along definite lines, which are called *Lines of Force.*

(*b*) Substitute a sheet of glass for the cardboard, and repeat the experiment. Make in your note-book a sketch of the figure obtained.

(*c*) Similarly obtain the lines of force for a horse-shoe magnet, and for the following combinations:

(1) Two bar magnets in the same straight line, with opposite poles an inch apart.

(2) Same arrangement, only similar poles, an inch apart.

(3) Two bar magnets arranged parallel with similar poles near one another (Fig. 148).

(4) Two bar magnets arranged parallel with opposite poles near one another (Fig. 149).

(5) One pole of a bar magnet held vertically under the piece of cardboard.

Magnetic attraction and repulsion.—Experiments like those just described teach the rule referred to as the "First Law of Magnetic Attraction and Repulsion," which can be stated thus:

Like magnetic poles repel one another.
Unlike magnetic poles attract one another.

It must, however, be noticed here that, although repulsion is sufficient proof that two like poles are acting upon one another, attraction is not necessarily due to the mutual action of two unlike poles, since, as has been seen in Expt. 50. i. *e*, magnets can attract unmagnetised iron which has no poles at all.

Why a magnetic needle points to the north.—A compass needle always arranges itself with its marked or *N* end towards the magnetic north, because the earth acts like a bar-magnet. A certain part of the earth in the northern hemisphere acts like the unmarked or south-seeking end of the magnet, and attracts the marked end of the needle. The place where this attractive force is greatest is called the *north magnetic pole*, and though at first it seems contradictory, there must evidently be the south-seeking kind of magnetism at the north magnetic pole. The line in which the needle arranges itself is called the *magnetic meridian*. The student must avoid the common error of believing that the south pole of a magnet points towards the north. The *north* pole of a magnet points towards the north; and the question as to the kind of magnetism at the earth's magnetic poles does not affect the names given to the poles of a compass needle or magnet.

Lines of force.—When a bar magnet is covered with a sheet of card or glass, and iron filings are sprinkled on the card, if the card is tapped the filings arrange themselves along definite lines. The filings chiefly collect round the ends, which contain the *poles* of the magnet. The poles are placed near the ends of the bar-magnet, where the magnetic power is most strongly shown. A line joining the poles is called the *magnetic axis*. A line at right angles to the axis and midway between the poles is known as the *neutral line or magnetic equator*. It has been

seen that there are no filings along this line, where the opposite magnetic properties appear to neutralise one another.

When two magnets are placed near one another, the lines of force due to their mutual action can be shown by means of iron filings. The curves in which the filings arrange themselves indicate the direction of the resultant magnetic force.

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51. MAGNETIC DECLINATION.

i. **Magnetic meridian.**—(*a*) Remove all magnets, also any pieces of iron, to a distance. Support a bar magnet in a stirrup, and see that it swings freely (Fig. 150). Allow it to come to rest, and then draw a chalk line on the table, marking the line along which the magnet arranges itself. One way of doing this is to make marks on the table immediately below the middle points of both ends of the magnet by the help of a plumb line, and then to join the marks by means of a straight edge. Or, you may draw a line accurately parallel to one of the long sides of the magnet. But the best plan is to fix two needles vertically at the ends of the magnet, as in Fig. 150, and draw a line between them. Then turn the magnet over, so that the top becomes the bottom, and draw another line. The mean position between the two lines thus drawn is the magnetic meridian.

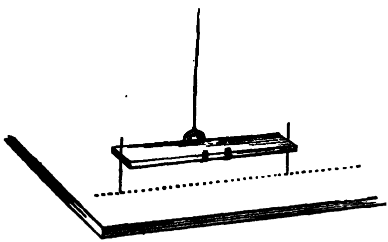

FIG. 150.—How to arrange a magnet to determine the direction of a magnet's north and south line.

(*b*) Freely support above this line each of the magnets you have in order, viz., the shaped lodestone, the magnetised needles, and the horse-shoe magnet. The horse-shoe magnet is best supported vertically by a thread. Notice that on coming to rest they all arrange themselves along the magnetic meridian.

The line along which a freely suspended magnet arranges itself is known as the magnetic meridian, and it can be at once *roughly* traced for any place by the simple experiments you have performed.

ii. **How to find the geographical meridian.**—Allow a freely-suspended compass needle to come to rest. Draw a line on the table to mark the direction of the needle. Through the point under the spot where the needle is supported draw a line inclined to the *magnetic meridian* you have just drawn, and at an angle to it equal to the magnetic declination of the place, which can be found from Fig. 151. The lines running from top to bottom are lines of equal magnetic declination, and the numbers at their ends show the

number of degrees by which the north pole of a magnet sets west of true north at the present time in the British Isles.

Declination, or variation.—The magnetic poles of the earth do not coincide with its geographical poles. You will see, as the

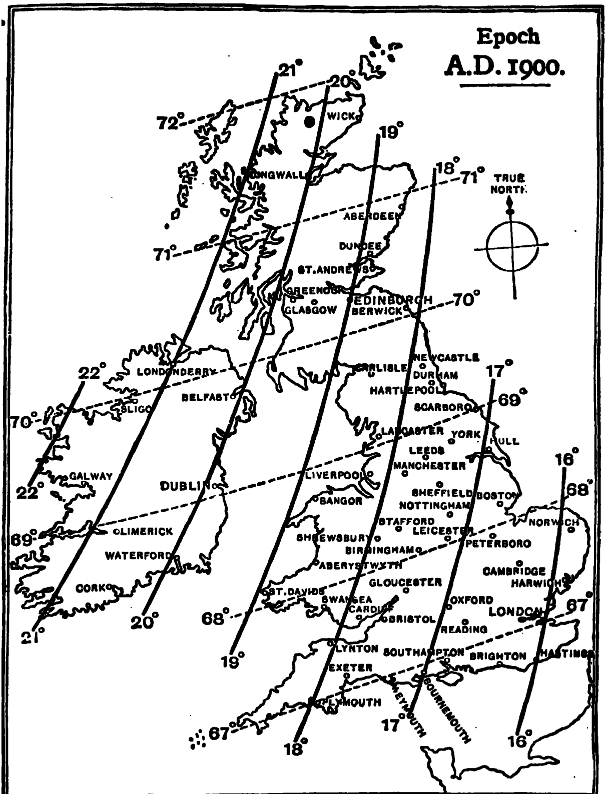

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FIG. 151.—The lines running down the figure show where the magnetic declination is the same; the broken lines across the figure connect points of equal magnetic dip. (From Prof. S. P. Thompson's *Lessons in Electricity and Magnetism*. (Macmillan.)

chapter proceeds, how the former are located. Great circles round the earth, which pass through the geographical poles, are

known as the meridians of longitude. Similarly, curved lines pointing to the magnetic north and south poles of the earth are called *magnetic meridians*; and it is along one of these that a compass needle arranges itself. *The angle between the geographical and magnetic meridians of any place is called the declination or variation of that place* (Fig. 152). Its value for any year at various places is recorded in the *Nautical Almanac.* At Greenwich Observatory in 1900 the declination was 16° 34′ W. Having a compass needle and knowing the angle of declination it is easy to determine the geographical meridian through a place. The direction in which the compass sets itself is found, and then allowance is made east or west of this according to the declination of the place of observation.

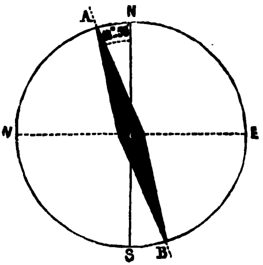

FIG. 152.—Magnetic declination is the angle between the magnetic and geographical meridians of a place.

52. MAGNETIC DIP.

i. **Meaning of magnetic dip.**—Take a knitting needle and support it by a fibre or two of unspun silk, attached by soft wax, so that it arranges itself horizontally. Now, holding it carefully so as not to break the silk, magnetise it by the method of Expt. 49. iv. Allow it to again hang freely. It is no longer horizontal. One end *dips* down. By means of a compass needle ascertain which pole is dipping, and record your result.

ii. **Construction of a dipping needle.**—A needle which is free to move on a vertical plane, but fixed as regards movement in a horizontal plane, is called a dipping needle. Either use a bought dipping needle, or make a simple form yourself such as the following:

Select an unmagnetised knitting needle about 6 ins. long. Construct an axle for the needle in the following manner: Hold two short pieces of copper wire on opposite sides of and at right angles to the length of the needle. Twist the ends of the wires together on each side so as to grip the needle tightly, and carefully straighten the twists. Make the wire surfaces as smooth as possible by heating in a gas flame and applying sealing-wax, shaking off the excess of wax while still fluid. Apply a spot of sealing-wax so as to rigidly connect the axle to the needle. Make a support for the needle by cutting two rectangular pieces of sheet brass or copper (3 ins. × ½ in.), rigidly connect them together at the base with their short edges horizontal and ½ in. apart, and fix them to a suitable

base-board. Attach a circular scale of 90° to one of the supports (Fig. 153). See whether the needle is truly balanced by supporting it by its axle on the knife-edges; if necessary, adjust the position of the axle by slightly warming the sealing-wax joint and moving the axle along the needle. Carefully magnetise the needle. Place it on the knife-edges with its axle coinciding with the centre of the circular scale.

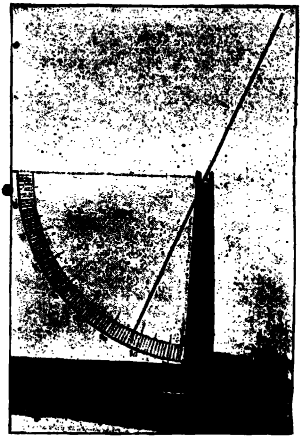

Fig. 153.—Simple form of dip needle, devised by Mr. H. E. Hadley.

iii. **Determination of the angle of dip.**—(*a*) To make an accurate measurement of this angle you must be sure of one or two things. *The needle must move in the plane of the magnetic meridian.* One plan to ensure this is as follows: Carefully draw the magnetic meridian by Expt. 51. i. *a*, and then arrange the needle so as to lie directly above it. When set free the needle moves in the plane of the meridian.

(*b*) A better way, and the plan generally adopted, is to first rotate the needle until it stands quite vertical, pointing to the zero divisions of the scale. Then turn the plane in which the needle is free to move through exactly 90°, thus making this plane to coincide exactly with the magnetic meridian.

iv. **Explanation of angle of dip.**—Magnetise a sewing needle as in Expt. 49. iv. Suspend it by a thread so that it hangs quite horizontally. Bring it over the neutral line of a bar-magnet, and notice that it remains horizontal. Gradually move it towards the north-seeking end of the magnet. Observe that as the pole of the magnet is approached the south-seeking end of the needle becomes inclined at larger and larger angles to the bar-magnet, until when it is over the end it is vertical. The angle which the needle makes with the bar-magnet corresponds to the angle of dip of a dipping-needle.

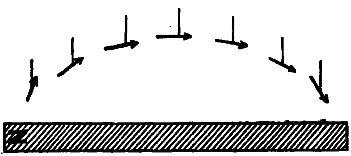

Fig. 154.—Dip of a small compass needle in different positions over a magnet.

A dipping needle is simply a magnetic needle suspended in such a way that it is free to move in a vertical plane in a manner similar to that in which the magnetised knitting needle

moves in Expt. 52. ii. Fig. 155 will make the principle of its construction quite clear.

A good form of the instrument is shown in Fig. 156. A magnetic needle, supported on a horizontal axis, is free to move vertically round a graduated circle. This circle is attached to a framework, which is carefully centred and so arranged that it can rotate about a vertical axis which passes through the centre of suspension of the needle. The centre of suspension should, moreover, be at the centre of gravity of the needle.

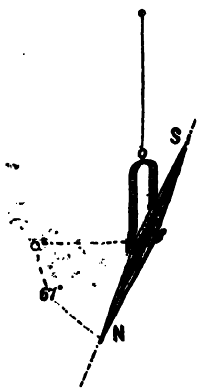

FIG. 155.--Magnetic dip at Greenwich.

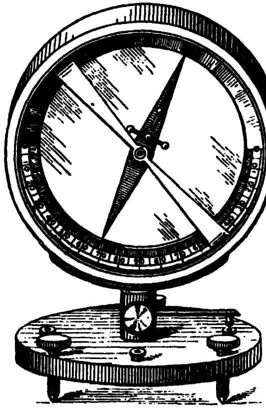

FIG. 156.—A portable dip circle.

When measuring the angle of dip at a place with such an instrument, the framework is slowly rotated until the needle stands vertical. When this condition of things is obtained the plane of the needle is at right angles to the magnetic meridian. The framework is consequently rotated through 90 degrees in order to bring it into the plane of the magnetic meridian, and *the angle between the horizontal line and the dipping half of the needle* is an exact measure of the angle of dip at the place of observation. There are several important adjustments to obviate any error in the suspension of the needle which the interested student will find explained in books on magnetism. The values of the magnetic dip in different parts of the British Isles are shown by broken lines running across Fig. 151. The numbers show the angle by which the north pole dips down. At Greenwich in 1900 the magnetic dip was 67° 10′.

Behaviour of the dipping needle at different places on the earth's surface.—It has been seen that a needle assumes a horizontal position when above the neutral line, or magnetic equator of a magnet. When above the poles of the magnet the needle stands vertical, and in intermediate positions the needle is inclined at a greater and greater angle as the pole is approached. Moreover, over the north-seeking end of the bar-magnet the south-seeking pole of the needle is below, whereas over the other end of the bar-magnet the north-seeking pole of the needle is in the lowest position.

Precisely the same thing is observed in the case of the earth; in some places the dipping needle adopts a horizontal position, and a line joining all those stations where this is so marks the *magnetic equator of the earth.* When the needle is moved away from this equator towards one of the magnetic poles of the earth, the dipping needle makes a larger and larger angle with the horizon, or, what is the same thing, the angle of dip increases, until eventually the needle stands vertical, or the angle of dip is a maximum. When this is so we know that one of the magnetic poles of the earth has been reached.

Position of the earth's magnetic poles.—The magnetic poles of the earth, which are located by the vertical position of the dipping needle in their immediate neighbourhood, do not coincide with the geographical poles. The north magnetic pole, at which there must be south-seeking magnetism, because the north-seeking pole of the dipping needle is the one which dips, is situated a thousand miles away from the north geographical pole at Boothia Felix in lat. 70° 5′ N., and long. 96° 46′ W. Its position was discovered by Sir James Ross in 1831. Observations made by Mr. Borchgrevink during his Antarctic expedition in 1899 indicate that a south magnetic pole is situated in lat. 73° 20′ S. and long. 146° E. There is, however, every reason to suppose that there are two south magnetic poles.

The earth as a magnet.—The various phenomena, to which we have only been able to refer briefly, could be produced in a general way if a huge magnet or lodestone was arranged along a diameter of the earth with its south-seeking pole under the north magnetic pole (Fig. 157). The position taken by the dipping needle is that which such a bar-magnet would cause it to adopt. The neutral line of the bar-magnet would be the position of the magnetic equator of the earth, and the magnetic

poles of the earth would be over those of the magnet. The earth's magnetic condition can, however, be better represented by considering that there are two magnets within the earth, one much stronger than the other. Of course, it must be understood that no such gigantic magnets are hidden away in the earth's interior, but the illustration affords a ready means of remembering the chief points which have been enumerated.

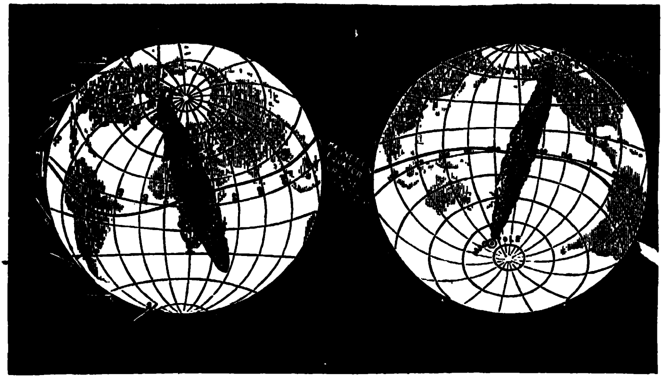

FIG. 157.—Diagrammatic representation of magnetic condition of the earth.

The mariner's compass.—Expt. 51. i. *b*. has shown that every suitably supported magnet arranges itself in the magnetic meridian, and it is on this fact that the mariner's compass depends for its construction. In the actual instrument, a flat needle is suspended by means of an agate cap, placed at its centre of gravity. The cap works on a point in such a manner that the needle can move freely in a horizonal plane. On the top of the needle a card, divided as shown in Fig. 158, is fixed, care being taken that the centre of the needle is under the centre of the card, and the north-seeking pole of the magnet under the division marked north on the card. This north point is indicated in the figure by means of the *fleur-de-lis*. With this arrangement the direction of the magnetic north pole is always seen by looking at the *fleur-de-lis*. The dotted line indicates the direction of the middle line, from bow to stern, of the ship upon which the compass-card in the figure is supposed to be. When the man at the helm wishes the ship to travel in

any particular direction, he turns the wheel until the required point of the compass comes under the arrow on the dotted line. In Fig. 158 the compass card indicates that the ship, the medial line of which is shown, is travelling in a N.N.E. direction.

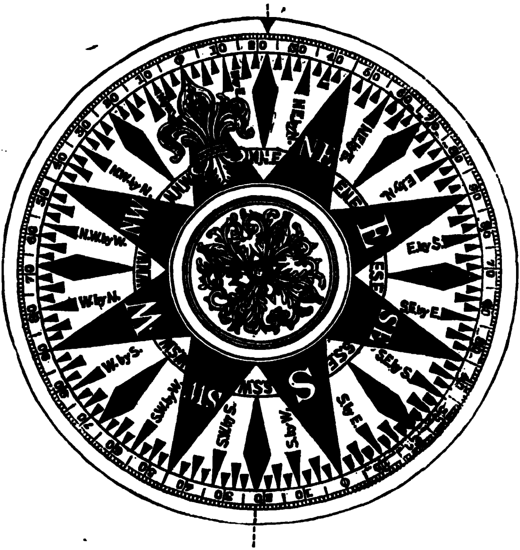

FIG. 158.—A compass card.

CHIEF POINTS OF CHAPTER XIV.

Lodestone is a natural chemical compound of iron and oxygen which possesses the property (1) of attracting iron and steel filings; (2) of coming to rest in a magnetic north and south line when freely suspended or balanced.

Artificial magnets have the same properties as lodestone; they can be made by stroking a piece of steel in one direction with a lodestone or a magnet. In every respect artificial magnets have the same magnetic properties as lodestone.

The primary law of magnetic attraction and repulsion is:—like poles repel each other; unlike poles attract each other.

When a magnet is broken, each of the resulting parts is a magnet possessing both a north- and a south-seeking pole.

Magnetic declination or variation is the angle between a true north and south line (shown by a noon-day shadow) and a magnetic north and south line (shown by a compass needle). It differs at different places.

Magnetic dip or inclination is the angle which a magnetic needle turning about a horizontal axis makes with the horizon when the vertical plane in which it moves coincides with the magnetic meridian.

A dipping needle simply consists of a magnet supported on a horizontal axle and free to move in a vertical plane. The needle must swing exactly in the magnetic meridian before the angle of dip at a place is measured.

The earth's magnetic poles are the points through which magnetic meridians pass, and at which a dipping needle would set vertically. The north magnetic pole is in Boothia Felix, and a south magnetic pole is at lat. 73° 20′ S., and long. 146° E.

EXERCISES ON CHAPTER XIV.

1. A magnetic needle balances so that it is free to turn in any direction, either upwards or sideways. How will it settle? The experiment is performed in England. (P.T., 1898.)

2. Suppose you are given a small compass and two knitting needles, of which one is slightly magnetised and the other unmagnetised. How will you find (1) which needle is which, and (2) which is the north-seeking end of the magnetised needle? (P.T., 1898.)

3. A bar-magnet is broken into four pieces. What magnetism do these pieces possess? How can you prove the truth of your answer? (P.T., 1898.)

4. Two compasses are put near together on a table. In what positions may the needles be expected not to disturb one another? How will the needles behave when one compass is put to the magnetic north-west of the other? (P.T., 1898.)

5. A magnet is embedded in a piece of wood. How can the position in which it lies be determined without breaking the wood?

How could you determine the magnetic north and south direction by means of such a hidden magnet? (P.T., 1897.)

6. Explain the meaning of the following:

(*a*) The mean declination at Greenwich in 1896 was 16° 56′·5 west.

(*b*) The mean dip at Greenwich in 1896 was 67° 9′. State why it is necessary to specify the place and the year in which the observations were made. (P.T., 1897.)

7. If you were provided with a small magnetic needle upon a pivot, and also with two bar-magnets, how would you determine (*a*) which is the north pole of the needle, (*b*) which is the north end of each of the magnets, (*c*) whether the two magnets are of equal strength or not?

8. What is the "dip" of a magnetic needle? Why is it greatest at the magnetic poles? (1896.)

9. Describe the mariner's compass and its chief uses. (1895.)

10. Describe the behaviour of a magnetic needle mounted on a horizontal axis in the neighbourhood of London. State what would happen if it were carried: (*a*) Towards the equator; (*b*) Towards the north pole. (1899.)

11. Describe an experiment by which the laws of attraction and repulsion by magnets can be easily demonstrated. (1899.)

PART II.: CHEMISTRY.

CHAPTER XV.

CHEMICAL CHANGES IN RELATION TO QUALITY AND QUANTITY OF MATTER.

53. MIXTURES AND COMPOUNDS.

i. **Mixture and compound.**—Procure some flowers of sulphur or powdered roll-sulphur and some copper powder,* and shake them together, in the proportion of four parts by weight of copper to one of sulphur. The result is a mixture of sulphur and copper, the colour of which will be between the yellow of sulphur and the red of copper. If the mixture be examined with a magnifying glass, there will be no difficulty in recognising the particles of sulphur and copper lying side by side.

Place a little of the mixture in a test-tube, and pour some carbon bisulphide upon it, and shake well. By this means all the sulphur is dissolved and the copper is left behind.

Now heat another portion of the mixture in a dry tube, and carefully notice what happens. First the sulphur melts, and, as the copper gets hot, it suddenly becomes very bright. Allow the tube to cool, and break it to examine its contents. It is neither yellow, the colour of sulphur, nor red, the colour of copper, but almost black. An examination with the magnifying glass reveals no particles of sulphur and no copper filings. No part of the mass will dissolve in carbon bisulphide.

ii. **Gunpowder is a mixture.**—Procure enough gunpowder to cover a crown; put it in a small flask, and well cover it with water. Heat the flask gently for some minutes over wire gauze placed above a

* The copper powder is easily prepared by digesting granulated zinc in a solution of copper sulphate.

burner, and then filter what remains in it. Collect the filtered liquid in an evaporating basin and evaporate it to dryness, when a white substance will be left, which is nitre. Scrape the black residue off the filter-paper and shake it up with carbon bisulphide. Filter this solution through a new paper, and again collect the liquid in a basin. Place the basin away from all flames, and leave it exposed for a little time to the air, and the liquid, which is very volatile, will disappear, leaving the brimstone behind in the form of beautiful crystals. The charcoal which is left on the paper should be dried, and a part of it may be burnt to show its real nature.

Physical and chemical changes.—Matter is subject to two kinds of change. Hitherto we have only been concerned with those which influence the properties of matter, leaving its composition unaltered. It has been seen that a body, such as a piece of iron, may gradually increase in temperature, changing from cold iron to hot, and, becoming hotter and hotter, may change in colour, passing from a dull gray to red, and from red to almost white, eventually becoming incandescent and emitting light rays. But if left to itself the iron will begin to cool, passing through the same changes in the reverse order until it reassumes precisely its former condition.

Or, again, we might take a piece of soft iron, and, having wound silk-covered copper wire round it several times, pass an electric current through the wire. It would be found, on examining the iron, that new properties had been imparted to it, that it was now able to pick up other pieces of iron, or had become magnetised. If the electric current be discontinued, the new power, too, disappears.

Such changes as these, where the substance or composition of the body remains unchanged, are known as *physical changes.*

On the other hand, if a piece of iron be left exposed to damp air for some hours it becomes covered with a reddish-brown powder, which the most superficial examination will show is a different substance from the iron with which we started. There is a very large number of changes of the same kind as this continually taking place around us. When gunpowder explodes, we have an abundance of smoke formed and a black residue left behind, and it is easy to see that the smoke and deposit are quite unlike the gunpowder before the flash. Such changes as these are called *chemical changes.* It is with changes of this second kind that Chemistry is concerned, and we may define this science thus: *Chemistry is that branch of knowledge which deals with chemical changes; those, namely,*

which result in the formation of new substances with new properties.

Chemical elements.—The result of a large number of experiments, made from time to time by different chemists, has been to show that there are upwards of seventy different forms of matter which can by no known methods be broken up into anything simpler. By this is meant that if any one of these, such as pure gold or silver, be selected and treated in any way with which chemists are familiar—for example, if it were subjected to a very high temperature—nothing could be obtained from it having properties different from the properties of gold or silver, as the case may be. Bodies of this simple kind are called *elements.*

But it must be carefully borne in mind that as the methods which chemists adopt become more and more refined, it is quite likely that some of these may be found to be wrongly regarded as elements. Up to the time of Davy (1807) the substances soda, potash, and lime were regarded as elements. He found, however, that they could be split up into simpler constituents. From soda he obtained a soft metal, sodium, and two gases, oxygen and hydrogen, and from that time, of course, soda could not be regarded as an element. Similarly, if at any future time it should be found that any of the forms of matter which we call elements can be split up into simpler bodies with different properties, the element which is thus decomposed will have to be struck off the list. Of the elements known to chemists, six at least exist in the gaseous state under ordinary conditions of temperature and pressure. These are chlorine, fluorine, hydrogen, nitrogen, oxygen, and argon. Two of them, bromine and mercury, are liquids. The rest are solids, and some of the commonest are given in the table.

SOME OF THE COMMONEST ELEMENTS.

Gases	*Solids*	
Chlorine	ALUMINIUM	LEAD
Fluorine	ANTIMONY	MAGNESIUM
Hydrogen	Arsenic	MERCURY
Nitrogen	BARIUM	Phosphorus
Oxygen	BISMUTH	POTASSIUM
Argon	CALCIUM	Silicon
	Carbon	SILVER
Liquids	COPPER	SODIUM
Bromine	GOLD	Sulphur
Mercury	Iodine	TIN
	IRON	ZINC

Metals and non-metals.—A good many of the elements are possessed of certain distinctive characters in which they resemble one another. They have a bright lustre, a high specific gravity (p. 19), are good conductors of heat and electricity, and are known to chemists as *metals*. There is no difficulty in deciding in a large number of instances that the element possesses the characters of a metal, and the student will immediately think of gold, silver, copper, iron, etc. Other elements, however, are quite as plainly not of this class; they have no lustre, they are not heavy, nor do they conduct heat and electricity well. These are spoken of as *non-metals*, and phosphorus, sulphur, and carbon will serve as good instances. But the line between the two classes is not a hard and fast one, for one or two of the elements possess some of the properties which distinguish a metal, and yet for other reasons, which the student will understand better later, are not classed with the metals, but with the non-metals. Arsenic may be cited as an instance of an element which possesses properties common to both classes. In the list of elements given in the preceding paragraph the metals are printed in capitals (see also Chapter xxiii.).

Mixtures and compounds.—The differences between a mixture and a compound will be most easily understood by carefully performing the experiment described above with flowers of sulphur and copper powder. By merely mixing these things together no change in their properties is brought about. By suitable mechanical means they are easily separated. But if the mixture is heated strongly, a profound and permanent change ensues.

What is this great change which has resulted from heating the two elements together? Clearly that it has resulted in the formation of a new substance with properties of its own. Such a change as this is known as a *chemical change*, and is said to be the result of *chemical action*. The new substance formed from the copper and the sulphur is called a *chemical compound*, and in this particular case there are two elements held together by a force which is known as *chemical attraction*. We are now in a position to enumerate the peculiarities and distinguishing characteristics of mixtures and compounds.

Mixture.—*In a mixture the components exist side by side, and can be separated by suitable mechanical methods. The components are not held together by chemical attraction, that is, they are not*

chemically combined. The ingredients can be present in any proportion, and the properties of the mixture are intermediate between those of the constituents.

Compound.—*A chemical compound is a substance which can be split up into two or more elements. Its constituents are held together by chemical attraction, and cannot be separated by any ordinary mechanical means. It always contains definite masses of the elements composing it, and its properties differ entirely from those of its constituents.*

Familiar examples of mixtures and compounds.—It will not be difficult to find many examples of mixtures which are familiar to every one. Gunpowder, for instance, is a mixture of three things—nitre, brimstone, and charcoal. They are, however, so thoroughly mixed that there is more difficulty in separating the ingredients than is experienced in the case of a mixture of flowers of sulphur and copper powder. The nitre can be separated from the brimstone and charcoal by shaking the gunpowder up with water. After filtering off the water, the brimstone can be obtained free from charcoal by shaking the residue, after treatment with water, with carbon bisulphide. The sulphur is dissolved and the carbon left. This shows that the constituents of the gunpowder are not held together chemically but exist side by side. In a similar way the student will have no difficulty in understanding that the amounts of the nitre and other things can to some extent be varied, and that in all particulars the gunpowder fulfils the conditions of the definition of a mixture.

Another familiar mixture is found in the air we breathe. This is made up of nitrogen and oxygen mixed in the proportion of four parts by volume of the former to one of the latter. The reasons for considering the air to be a mixture will be better understood a little later (p. 225).

From these examples it will be seen that mixtures can be made up of either elements or compounds.

The simplest chemical compounds contain two elements only and are called *binary compounds*, such as water, lime, common salt. Many others contain more than two elements, and chalk and clay can be mentioned as instances. As we proceed, the student will become familiar with many other instances of chemical compounds of varying degrees of complexity, from the binary compounds to those containing several elements (p. 290).

54. INDESTRUCTIBILITY OF MATTER.

i. **No loss of matter accompanies chemical change.**—(*a*) Put a little red phosphorus in a flask or large test-tube, and insert a well-fitting cork, and weigh the whole. Set fire to the phosphorus by holding the flask near a flame, after it has cooled down again weigh the whole apparatus. The mass will be practically the same in both cases, because nothing has been added or taken away from the total quantity of matter contained in the flask.

(*b*) Place a small piece of magnesium ribbon in a porcelain crucible having a lid, and determine, by weighing, the mass of the ribbon and crucible. Then ignite the magnesium, and when it has burned out again find its mass. The mass will be found greater than before.

(*c*) Connect two flasks containing a little hydrochloric acid and ammonia respectively, and fitted with india-rubber stoppers having a single hole, through which a piece of glass tubing passes. Suspend the whole apparatus from a balance, and counterpoise it. Notice that a white cloud gradually forms owing to the combination of the two gases. But though these solid particles forming the cloud are produced, the counterpoise is not disturbed; therefore the mass has not changed.

ii. **Moisture is formed when a candle burns.**—Over a burning candle hold a clear cold tumbler, which has been carefully dried inside and out. Notice that the inside of the tumbler becomes covered with mist, and, after a short time, drops of water are formed which run down the sides of the tumbler.

iii. **Properties of the gas left after a candle has burnt in air.**—Wind a piece of copper wire round a small candle, as shown in Fig. 159, and light the candle. Push the top of the wire through a small hole in a disc of cardboard, and then lower the candle into a dry, clean glass bottle in such a manner that the top of the jar is covered by the cardboard disc. Observe that the flame of the candle becomes dimmer and dimmer, and soon goes out altogether. Water collects on the inside of the jar as in the last experiment. Take out the candle and cover the jar with a greased glass plate.

FIG. 159.—Candle supported so that it may be burnt in a bottle.

To find out something about the gas left in the jar:

(*a*) Quickly insert a burning taper, or the relighted candle; it is at once put out.

(*b*) Pour in a little fresh, clear lime-water, and shake it up in the jar; notice that it is turned milky.

iv. **Gain of mass when a candle burns.**—Obtain a lamp glass like the one shown in Fig. 160. At the narrow part arrange a tray of coarse wire gauze. On the shelf so formed put pieces of caustic soda. Fit a large cork, with several holes through it, into the

bottom of the lamp glass. Through one hole in the cork insert a candle. By weighing, find the mass of the whole apparatus. Withdraw the cork, light the candle, and reinsert the cork. After the candle has burnt for a few minutes, blow out the flame, and when the apparatus is cool make another weighing. It will be found that the apparatus has increased in mass.

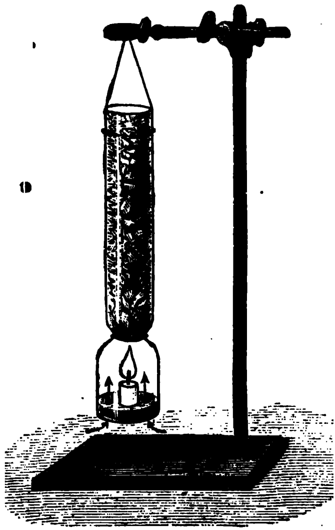

FIG. 160.—Lamp glass containing substances to absorb the vapours and gases produced when a candle burns.

No kind of matter can be destroyed.—There is a certain fixed amount of matter in the universe which never gets any less and never any greater. If we confine our attention to the earth, we cannot say that it never receives an addition to the matter of which it is built, for every year it is receiving numbers of small solid bodies which continually fall upon its surface from outside space. But the statement means that in those cases in which it is popularly supposed there is a loss of matter, no such destruction takes place, but only a change in the form assumed by the matter. This will be made quite clear if what really takes place in a number of cases, where a loss of matter appears to have occurred, is considered.

There is no loss of matter in certain familiar changes.—To the casual observer it appears as though water disappears when it evaporates from a vessel containing it; and a solid which like sugar vanishes from sight as it dissolves in water may seem to be lost. Similarly, it looks as though it may be an open question whether any change has taken place in the amount of matter when a piece of ice is converted into water, or a quantity of lead is changed into a liquid. It was only the application of the experimental method of inquiry which could properly answer these questions. It has been found by careful

weighing that no loss of matter takes place in any of these cases.

Even in instances where a loss of matter at first sight seems certain, the same process of weighing demonstrates conclusively that no such loss takes place. A candle does not really cease to exist as it burns away. It no longer exists as a candle it is true, for the materials of which the candle is made assume new forms, but they can all be accounted for.

The burning of a candle.—The candle ceases to exist as tallow or wax, or whatever it is made of, and assumes new forms, still material—one liquid, the other a gas which turns lime-water milky. When all the liquid formed and all the gas which turns lime-water milky are weighed, it is found that these two things together actually have a greater mass than the part of the candle which has disappeared. The reason why there is an *increase* of mass will be explained later. One way to prove this is by the apparatus shown in Fig. 160. The candle is burned in a wide tube, fitted with a cork at the bottom with holes in it to allow the air, which is necessary to help the candle to burn, to pass in. The tube is filled with a substance which has the power of arresting the products of the burning. Such a substance is caustic soda, which is used in the form of lumps. Air is drawn through the apparatus as shown by the arrows.

Before the experiment is started, the candle is weighed with the tube containing the lumps of caustic soda. After the experiment the same things are weighed over again. It will be found that the tube has increased in mass to a greater extent than that of the candle has been diminished. We may be quite sure, therefore, that there has been no loss of matter. The gain is due to a gas taken from the air by the candle when burning.

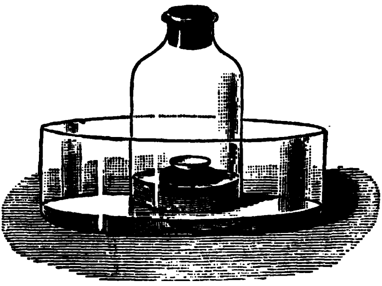

FIG. 161.—Phosphorus on burning uses up one-fifth of the air in the bottle, and water rises to take the place of the air used.

The burning of phosphorus.—When phosphorus is allowed to burn in a closed flask, as in Experiment 54. i. *a*, there is

no alteration in the quantity of matter before and after the burning, as can be shown by weighing. What happens in the flask is very simple, though probably it will not be fully understood until after the next chapter has been studied. In the first place there is phosphorus and air in the flask. When the phosphorus takes fire, a white powder, which looks like white smoke, is produced. Upon opening the flask there is found in it a gas in which a lighted candle or a taper will not burn. The white fumes formed by the combustion of the phosphorus are found as a white substance condensed upon the inside of the flask. Substances completely different from phosphorus and air are thus formed by the burning of the phosphorus, but though the forms of matter are changed by the action the quantity of matter remains the same.

CHIEF POINTS OF CHAPTER XV.

Physical changes are those in which the composition of the body experiencing the change remains unaltered. The science concerned with these changes is called *Physics*.

Chemical changes are those which result in the formation of new substances with new properties. The study of such changes is called *Chemistry*.

Chemical elements are kinds of matter which can, by no known means, be broken up into anything simpler. They can be subdivided into *metals* and *non-metals*.

Compounds and mixtures.—

Substances
- Elements
  - Metals
  - Non-metals.
- Compounds, elements present in definite proportions.
- Mixtures, constituents present in any proportion.

In a **mixture** the components exist side by side and can be separated by simple mechanical methods. The ingredients may be present in any proportion, and the properties of the mixture are intermediate between those of the constituents.

In a **chemical compound** the components cannot be separated by the simple means available in the case of mixtures. The properties of the compound are quite different from those of the constituents, and the constituents are always present in certain definite proportions which for each compound are invariable.

Indestructibility of matter.—There is no loss of matter in any kind of change. Matter cannot be destroyed. All chemical changes take place without loss of matter. Chemical changes result in the formation of new substances with new properties; but the new com-

pounds have the same mass as the materials out of which they are formed. Thus, when a candle burns, new substances are produced, the mass of which is the same as that of the part of the candle which disappears and the part of the air used up in the burning of the candle.

EXERCISES ON CHAPTER XV.

1. Explain the terms Mixture and Compound. How would you show that iron and sulphur can exist together, either as a mixture or as a chemical compound? (1897.)

2. State in general terms the differences observable between a mixture and a compound of any two substances. Use air and water as illustrations. (1898.)

3. Which of the following substances are elements, which chemical compounds, and which mixtures, and what are the elements of which they are composed:—Air, hydrogen, quartz, gunpowder, lime, nitrogen, charcoal, iron? (1898.)

4. Which of the following bodies are "elements":—Air, chalk, coal-gas, diamond, iron, mercury, salt, soot, sulphur, water?

Give your reasons for thinking that any one of the ten is not an element. (P.T., 1898.)

5. Describe some differences between a chemical compound and a mixture. Gunpowder is a mixture of nitre, sulphur, and charcoal. How can these ingredients be separated from one another? (P.T., 1897.)

6. When a candle burns in air, certain substances are produced which differ from the wax of the candle and from air. How would you prove this to a class? (P.T., 1897.)

7. Describe fully an experiment with which you may be familiar to prove that matter is indestructible. (1899, Day.)

8. Ancient philosophers regarded earth, air, fire, and water as the four elements of which our world is composed. What has modern chemistry to say as to the nature of these so-called elements? (P.T., 1897.)

9. How can you show that gunpowder is a mechanical mixture of three different substances? (1900.)

10. Describe an experiment showing that water and carbon dioxide are formed in the combustion of a candle. How can ordinary coal-gas be made to burn with a non-luminous flame? (London Matric., 1900.)

CHAPTER XVI.

NITROGEN AND OXYGEN AS CONSTITUENTS OF AIR.

55. THE AIR.

i. **Iron in rusting gains in mass.**—Weigh carefully a watch glass with some iron filings or tacks, add a few drops of water (because iron rusts best in the damp) and allow it to stand. At the end of a few days warm gently to drive off the water, and when *quite dry* again weigh, and note carefully the mass. Has the iron gained or lost?

ii. **Iron in rusting abstracts one constituent of air.**—(*a*) Place some iron filings in a muslin bag and tie the bag to a piece of glass rod. Moisten well (better dip it in a solution of sal ammoniac) and place it in a bottle of air inverted over water (Fig. 162). Examine after a few days. It will be seen that the water has risen in the glass, showing that some part of the atmosphere has been abstracted by the iron in rusting.

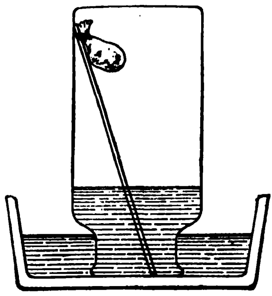

FIG. 162.—Iron in rusting takes up the active part of air.

(*b*) Tightly place your hand on a card under the mouth of the jar so as to allow no water to escape, set the jar upright and place a burning taper into it. Note what happens, *but do not throw away the water.*

iii. **Volume of the part of the air abstracted.**—Next measure in a graduated vessel the quantity of water in the bottle. This is equal to the quantity of gas which has been used by the iron. Also measure the quantity of water the bottle holds. This is the quantity of air it originally held.

iv. **Action between hot copper and air.**—Place a roll of copper gauze or some copper turnings in a hard glass tube provided with a bored cork at each end. Find the mass of the tube and the copper. Connect one end of the tube with an aspirator or a bottle fitted as in Fig. 163, so that air can be made to pass through the tube. Con-

nect the other end of the hard glass tube with a tube passing under a jar standing inverted in a basin of water. Heat the copper to redness and drive air over it by letting water run into the corked bottle. Notice that the copper turns black owing to its combination

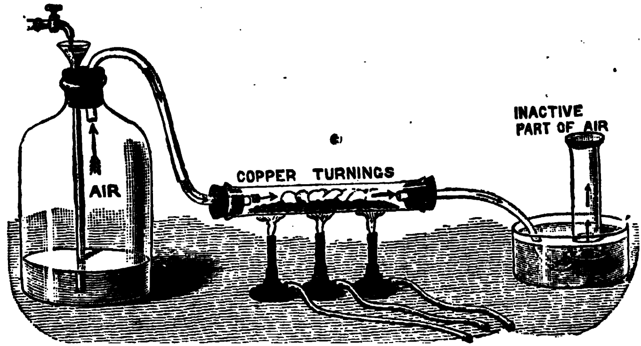

FIG. 163.—When air is passed over hot copper turnings it is deprived of its active part, and the inactive part can be collected as shown.

with the active part of the air. Allow the tube to cool, and by weighing redetermine the mass of the tube and its contents. The mass has increased. Lift the jar from the water and insert a lighted taper into it. The taper is extinguished, thus showing that the part of air required to sustain burning has been removed.

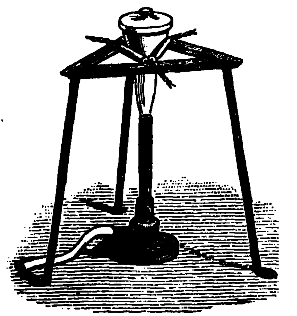

FIG. 164.—When magnesium burns it combines with the active part of the air and increases in mass.

v. **Gain of mass during burning.**—Weigh a crucible and lid and a piece of magnesium, which, folded lightly, is placed in the crucible. Heat strongly in a burner, taking care to let no fumes escape (Fig. 164). To do this, keep on the lid, and only raise it a little when the flame is removed. The magnesium is seen to burn brightly in places; but, if care is taken, no fumes are lost. When finished, the whole mass should be in the form of a white powder. Allow to cool, and weigh the crucible with the lid and powder. Subtract the mass of the crucible and lid to find the mass of the powder. It will almost certainly be found to be *more*, and, if the experiment is carefully done, it will be found that the magnesium has gained about 66·5 per cent.

Chemical examination of air.—In the study of Chemistry it is advisable to start with common and well-known substances, and to examine these as far as possible. The knowledge so obtained is then of service in the further study of other and less common substances. First, therefore, from its importance and its universal presence, the atmosphere should be studied. We know it to be a gas possessing weight and capable of exerting pressure (p. 92), but its chemical properties have not been examined. What is it composed of? How does it behave towards other substances? To answer these questions it will be necessary to study carefully the changes which different substances undergo when exposed to the influence of the atmosphere, selecting at first those changes which appear simplest. Of these, the rusting of metals—say, iron—may be chosen. The first problem to be solved is, what is this rusting? Does the iron lose or give up anything? Or, on the contrary, does it gain anything? To answer these questions it is only necessary to weigh carefully a watch glass with some iron filings or tacks and allow the iron to rust in the air, which will take a few days; on warming the rusty filings until quite dry and weighing again, it will be found, if care has been taken, that the iron has increased in mass, and the experiment has furnished the necessary answer, so that we may write:

Iron gains in mass during rusting.

The gain might have come from the water which was added, or from the atmosphere. To decide this point the rusting of the iron is allowed to take place in the apparatus shown in Fig. 162. The iron filings are enclosed in a muslin bag, which is placed in a bottle of air inverted over water. On examining after a few days the water will be seen to have risen in the bottle, showing that some part of the atmosphere has been abstracted by the iron in rusting, and the gas left behind extinguishes a lighted taper.

The taper being extinguished proves that the gas left in the jar differs from air in the respect that it does not allow substances to burn in it. Hence the material taken away from the air by the iron, which with the iron formed rust, is that part of the air which is concerned in burning, and we may state:

Iron in rusting gains in mass, taking some material from the air, and this material is the part of the air concerned in burning.

If now the volume of air left after iron has rusted in a closed

space is compared with the original volume it will be found that one-fifth of the air in the bottle is abstracted by the iron in rusting.

Rust of iron.—The reddish-brown substance which is formed when iron combines with the active part of the air (that is, with a gas called oxygen), in rusting, is not the only compound of iron with oxygen. The compounds which iron forms with the active part of the air are called *iron oxides* (p. 224), and the common rust of iron is only one of several oxides which are known. The commonest oxides are those which occur as minerals. One familiar to chemists as ferric oxide is fairly abundant in nature; it occurs as the beautifully crystallised mineral *specular iron ore*, found in Elba. It also makes up the mineral *haematite*, which goes under the names of *kidney ore* and *pencil ore* in the Furness district of Lancashire. Another common oxide of iron is that known as the black oxide, which makes up the minerals *magnetite* and *lodestone*. The black oxide is very often magnetic, though by no means always.

Part of the air can be removed by heated copper.—If air be passed over red-hot copper, the copper changes in colour and gradually increases in mass. If the remaining part of the air is examined by plunging a burning taper into it, the flame is extinguished. There is no difference between the condition of things in this case and in the rusting of iron, except that the copper must be strongly heated before it combines with the active part of air.

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56. NITROGEN.

Preparation of nitrogen.—(*a*) Read what is said about phosphorus on p. 218 and then place a little red (or yellow) phosphorus in a test-tube fitted with a good cork. Fix the stopper firmly in the test-tube. Hold the test-tube slantingly, by means of a test-tube holder, over a flame for a minute or two, so as to heat the phosphorus and make it burn. When it will burn no longer, take away the test-tube and let it cool for five or ten minutes. When cool take out the cork under water. Note that the water rises in the tube. Put back the cork and shake up; test the remaining gas; it extinguishes a burning taper. Measure the volume of the water; it is one-fifth that of the total volume of the closed tube (Fig. 165).

(*b*) Another method of preparing nitrogen is as follows:—Cut a small slit in a large cork, so that the small handle at the top of a crucible lid will fit firmly into it. Place the lid upon the cork, and float the cork upon the water contained in the pneumatic trough. Carefully cut off a piece of phosphorus as large as a good-sized pea, dry it, and place the lump upon the floating lid. The cutting

should be done under water. Ignite the phosphorus and slowly place over it a jar or a bottle without a bottom and fitted with a cork in its neck (Fig. 161). The bottle should have been divided as nearly as possible into five parts by pieces of paper gummed outside. Let the bottom of the bottle either rest on the shelf of the trough or on something suitable placed on the bottom. Allow the apparatus to remain for a few minutes, when the white fumes will have disappeared, and the water will be seen to have risen up to the level of the first division so as to fill one-fifth of the jar.

Pull the cork out of the bottle, and insert a lighted candle. The light is extinguished.

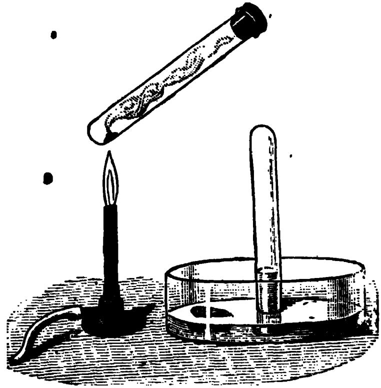

FIG. 165.—Preparation of nitrogen by removing oxygen from the air by burning phosphorus.

Chemical composition of air.—It has been found by burning phosphorous in air enclosed in different bottles at different times, and with different quantities of air, that the ratio of the volumes of the chief constituent gases in air is always roughly 1 : 5, and is independent of the size of the bottle, etc. Hence it is clear that this gives us the proportion of the *active part* of the air, and we may sum up the result of the experiments as follows:

Air contains 80 per cent. of the *inactive* constituent, which is called *Nitrogen*, and, as has been seen, does not allow things to burn in it; and the remaining 20 per cent. is the part concerned in burning, or the *active part* of air, its chemical name is *Oxygen.*

Properties of nitrogen.—The gas nitrogen is an example of a very inert element, since it can only with difficulty be made to combine with any other element. It does not burn, nor will it allow other substances to burn in it; or, as usually expressed, *it does not support combustion.* A mouse dies if put into this gas.

If the negative nature of the properties of nitrogen is borne in mind, and is considered in connection with the very active powers of oxygen, it will be understood that the presence of the

gas in the air serves the purpose of diluting the oxygen, weakening its powers, and making combustion much less intense than it would otherwise be.

If nitrogen obtained from air be heated with either magnesium or lithium it is found that about 1 per cent. of it remains unabsorbed. This residue is another substance present in the atmosphere to the extent indicated, and called *Argon*. Argon is also very inert, more so even than nitrogen. Owing to this, even until the year 1894, its presence in the air had been completely overlooked, although, nearly a century before, the eminent chemist Cavendish had unknowingly obtained some, regarding it as an impurity which he had overlooked—an example of the importance of giving attention to the minutest details in scientific investigations.

Phosphorus.—Phosphorus must be used with the greatest care. That you may employ it intelligently it will be advisable to state some of its chief properties in this place. From the table of elements on p. 205 you have learnt that it is a solid and non-metallic. It exists in two common forms known as *yellow* or *ordinary* phosphorus, and *red* phosphorus.

Yellow phosphorus very readily combines with the oxygen of the air. It is easily inflamed, the warmth of the hand being enough to cause it to catch on fire. *It must never be handled with the bare fingers.* Pieces of phosphorus should be moved from one place to another by a pair of forceps. Yellow phosphorus is always kept under water, in which it is insoluble. Whenever it is necessary to cut it the cutting should be done under water.

Yellow phosphorus easily melts, its melting point being 44° C. Though insoluble in water it easily dissolves in carbon bisulphide. It is very poisonous, and in the form of a vapour produces a disease of the bones. It is extensively used in the manufacture of matches, and is sometimes employed as a rat poison.

When heated to 250° C. in a sealed tube, or in any gas which does not combine with it, such as nitrogen, it is converted into red phosphorus. This variety of the element is not poisonous, and is insoluble in carbon bisulphide. It is not acted upon by the oxygen of air, and need not be kept under water.

57. PREPARATION OF OXYGEN.

i. **Preparation of oxygen from red oxide of mercury.**—(*a*) Place some mercury rust (known as red oxide of mercury) in a tube of hard glass closed at one end, and heat it strongly. Notice the darkening of the powder, also the dark deposit which collects round the inside of the tube above the powder. Place into the tube a splinter of wood which has been just extinguished and is still glowing. Note that it glows more brightly, or even bursts into flame. Allow the tube to cool, and notice that the powder returns to its original colour. With a piece of wood, or glass, scrape off the dark deposit from the walls of the tube. It is seen to be bright metallic quicksilver or mercury.

ii. **Preparation of oxygen from potassium chlorate.**—Powder some crystals of potassium chlorate; place the powder in a test-tube, and heat it. Observe that the mass crackles, melts, and gives off a gas. Test by a glowing match, and see that the gas is *oxygen*. The gas is, however, given off more readily, and without fusion, if a little manganese dioxide is added to the chlorate.

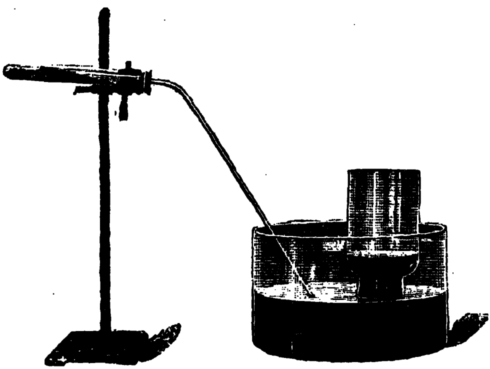

FIG. 166.—Preparation of oxygen by heating a mixture of potassium chlorate and manganese dioxide. The gas is being collected over water.

iii. **Preparation and collection of oxygen.**—(*a*) Into a hard glass tube, closed at one end, fit an india-rubber stopper, with one hole in it, through which a tube, bent as in Fig. 166, is passed. The other end of this tube, called the delivery tube, dips under water in a trough. Mix together some potassium chlorate and manganese dioxide, as in the previous experiment, and place the mixture in the tube. Support the hard glass tube and delivery tube as shown in the illustration. Fill several bottles with water and invert them in the trough. Gently warm the tube, and place one of the bottles of water over the end of the delivery tube. As the oxygen is driven

off, it displaces the water and gradually fills the bottle. When the bottle is full of oxygen, cover its mouth with a ground-glass plate, and lift it out of the trough. In this way fill five or six bottles with oxygen.

Caution.—Be careful not to take away the burner from under the hard glass tube before removing the delivery tube from the trough.

(*b*) Heat the mixture in the hard glass tube well, till no more oxygen is given off. Boil up the mass with water and filter it. The manganese dioxide remains unchanged on the filter paper. Evaporate the solution to dryness, and there remains a white solid which is not potassium chlorate and tastes something like salt.

Oxygen—the active constituent of air.—The next step is to obtain and examine the active part of the air which disappeared during the rusting of the iron. Knowing now that it is present in the rust, the most evident plan would be to endeavour to obtain it from this source. The ease with which iron rusts, that is, the readiness with which it takes up the active part of the air, should indicate that it would probably be very difficult to obtain it from this compound, and that some other rust which is more difficult to prepare would probably be better for our purpose. The most convenient is the rust of mercury, which is a red powder not easily formed.

Red oxide of mercury—the action of heat on it.—Red oxide of mercury, or, as it is sometimes called, red precipitate, can be obtained by heating metallic mercury for a considerable time in the air, when the oxide forms as a red scum upon the surface of the metal. A more convenient way of preparing it is, however, to heat the nitrate of mercury.

When red oxide of mercury is strongly heated, it darkens in colour and a dark deposit of mercury collects above the powder round the inside of the tube in which the heating is done. When a glowing splinter of wood is plunged into the tube it bursts into flame.

What does this experiment teach? It shows that by heating the rust of mercury we obtain mercury itself, and also a gas in which wood burns more brightly than in air. The gas thus obtained was taken out of the air when the mercury rusted, and it is given up when the rust is heated. As the gas which causes rust is the active part of air, it supports combustion very vigorously when obtained in this way without the diluting proportion of nitrogen.

It may be proved, by weighing, that the mass of the original mercury is equal to that left after the experiment, provided

that all the rust is decomposed and no mercury is lost. This shows conclusively that the gas escaping from the rust is the same gas as that taken from the air. This change may be thus stated :—*Oxide of mercury, when heated, decomposes into mercury and oxygen.*

Preparation of oxygen from potassium chlorate.—As the quantity of oxygen obtained by the method just described is comparatively small, and the oxide of mercury is expensive, a more convenient source of the gas is the white crystalline powder called Potassium Chlorate.

This white crystalline compound is made up of three elements—potassium, chlorine, and oxygen—and if heated, in the same way as the red oxide of mercury, it melts and gives off bubbles of oxygen, and after all the oxygen has been given off a white substance like table salt is left behind.

By heating, the potassium chlorate is broken up into two things, a gas and a white substance like common salt, which is called Potassium Chloride.

POTASSIUM CHLORATE	gives when heated	POTASSIUM CHLORIDE	and	OXYGEN.

Use of oxygen mixture.—By adopting a slightly different method, oxygen can be obtained more readily and easily, for it has been found that by mixing the potassium chlorate with certain other substances, of which one is a black compound, manganese dioxide, the oxygen from the chlorate comes off more easily and at a lower temperature. This mixture may be called *oxygen mixture.* If after all the oxygen has been driven out of the mixture the residue left behind is boiled up with water in a flask and the turbid liquid filtered, the manganese dioxide remains unchanged on the filter paper.

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58. PROPERTIES OF OXYGEN.

The jars of oxygen prepared as described in Experiment 57. iii. *a* are required.

i. **Physical properties of oxygen.**—Take one of the bottles of oxygen (one of those collected last should be chosen). Notice everything you can about the contents of the bottle. The gas in the bottle has *no colour.* Remove the plate from the mouth and test its smell; it has *no smell.* Try the taste by breathing some of the gas; it has *no taste.* See if the gas has any effect on moistened litmus-papers, one blue and the other red. There should be no effect; we say oxygen is a *neutral* substance.

ii. **The burning of a candle in oxygen.**—Attach a piece of stout wire to a wax taper, as shown in Fig. 159, and having lighted the taper plunge it into another of the jars of oxygen (Fig. 167). Notice that it is *not extinguished,* but continues to burn, but with a *larger* and *brighter* flame.

iii. **The burning of charcoal in oxygen,**—Into another jar of oxygen thrust a splint of wood red-hot at the end, or a piece of red-hot charcoal placed in a deflagrating spoon (a small upturned iron spoon with a long handle) (Fig. 168). Note the brilliancy of the combus-

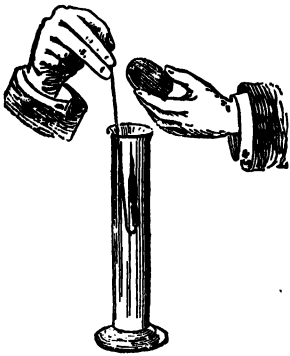

FIG. 167.—A candle burns in oxygen with a larger and brighter flame than in air.

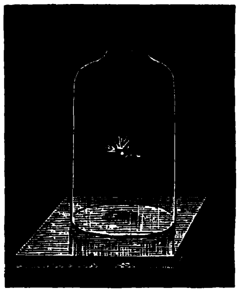

FIG. 168.—Carbon burns in oxygen with a much brighter flame than in air.

tion. Now pour into the jar some clear lime water (*i.e.* some of the clear liquid which is formed if lime and water be shaken together and allowed to stand. It is really a solution of lime in water). Notice that it turns milky owing to a white powder being diffused through the liquid.

iv. **The burning of phosphorus in oxygen.**—In another jar burn a piece of phosphorus about half the size of a pea, contained in the deflagrating spoon. Note the great brilliancy of the combustion and the dense white fumes. Add water and shake—the fumes dissolve. Into the solution put a blue litmus paper. Observe that it is turned *red.*

v. **The burning of sulphur in oxygen.**—Perform, with another jar, a similar experiment with sulphur. There are few fumes, but a strongly smelling gas is obtained, also soluble, turning blue litmus red.

vi. **The burning of magnesium ribbon in oxygen.**—Ignite a small piece of magnesium ribbon and hold it by means of crucible tongs in a jar of oxygen. Notice the white solid formed. Test its solubility in water, and show that unlike the previous products, it will not turn blue litmus solution red, but will turn red litmus solution blue.

vii. The burning of sodium in oxygen.—Put a small piece of sodium* in a dry deflagrating spoon, light the sodium, put it into another jar of oxygen. Observe the fumes formed. Dissolve these in water and try the effect of the solution on litmus paper. It does not turn the blue colour to red, but has exactly the reverse effect, and changes red litmus to blue. Feel the water; it has a soapy feel.

viii. The burning of iron in oxygen.—Obtain a piece of iron wire (a thin steel watch spring will do), and dip one end into a little melted sulphur, and when the sulphur is burning place the wire in another jar of oxygen. Observe that the sulphur burns and also starts the combustion of the iron which continues to burn with a brilliant shower of sparks. After the burning has ended, observe that a quantity of an insoluble solid (iron rust) has been formed.

ix. Oxygen is soluble in an alkaline solution of pyrogallol.—(*a*) Collect some oxygen in a test-tube over mercury. Dissolve a little caustic potash in pyrogallol, so as to make a strong alkaline solution. Force some of the solution into the oxygen by partly filling a bent pipette with it, and blowing down the pipette when the bent end is under the bottom of the test-tube, as shown in Fig. 169. Note that after a little while the oxygen is wholly absorbed.

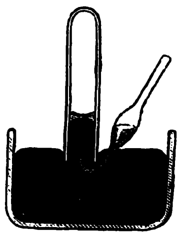

FIG. 169.—How an alkaline solution of pyrogallol can be introduced into a tube containing oxygen.

(*b*) Repeat the last experiment, substituting air for oxygen, and notice that the air is only partially absorbed.

Properties of oxygen.—Oxygen is a gas which has no colour, no smell, no taste. It has no action upon litmus paper, and is for this reason said to be neutral. Ordinary combustible substances burn more brightly in oxygen than in the air.

Oxygen has no effect on substances like sulphur and carbon when they are at the same temperature as the room, but if these elements are heated to the point of ignition the oxygen *combines* with them very readily, causing them to burn vigorously.

Some substances which will not burn under ordinary conditions can be made to burn in oxygen, and the case of iron affords a good example of this. The student should think of what the result would be if there were only oxygen in the air. As soon as iron got red-hot it would start burning. We could not in these circumstances use iron for our grates, furnaces, and similar things.

* Important! Carefully read the note on p. 229.

Oxygen is not very soluble in water—one hundred parts of water dissolve three parts of this gas. That the amount of oxygen dissolved by water is very small is seen by the fact that oxygen prepared for experiment is usually collected over water. But though the amount is small it is of great importance in the economy of nature, for it is due to this dissolved oxygen that water animals are able to breathe. Oxygen can, however, be readily dissolved by some liquids, such as a solution of pyrogallol in caustic potash.

Though oxygen exists in a gaseous condition under ordinary conditions of temperature and pressure, yet it can, by lowering the temperature and very much increasing the pressure, be made to assume the liquid condition.

Oxygen is indispensable to life. It is the constituent of the atmosphere which is used up in the processes of combustion, decay, and fermentation.

Formation of oxides explained.—Whenever oxygen combines with another element an oxide is formed. Indeed, oxygen is so active and powerful an element that it forms oxides with every element except fluorine.

In all the cases of burning studied experimentally when considering the properties of oxygen, new substances with new properties have been formed; they are therefore chemical compounds, and the experiments afford instances of chemical action. Taking some of the experiments performed as examples, when sulphur burns in oxygen a compound which has a distressing smell and reddens a blue litmus-paper is formed; it is called Sulphur Dioxide.

SULPHUR burning in OXYGEN forms SULPHUR DIOXIDE.

Similarly, when carbon burns in oxygen, a gas which extinguishes a burning taper and turns lime-water milky is formed. This compound is known as Carbon Dioxide.

CARBON burning in OXYGEN forms CARBON DIOXIDE.

Again, when iron burns in oxygen, a brown powder, which is really ordinary iron rust, is formed, as well as a brittle, black solid quite unlike the original iron. These compounds are both of them oxides of iron.

IRON burning in OXYGEN forms IRON OXIDE.

Air compared with oxygen.—We have now seen that when

a substance burns in oxygen a new compound is formed, which is an oxide. But we must go further, and ask—Is this also the case when a substance burns in air? Does the substance take away the oxygen and form an *oxide*, leaving the nitrogen unacted upon? This can be readily tested by burning phosphorus in a confined volume of air. As in the case of rusting, one-fifth of the volume of enclosed air is used, this being the quantity of oxygen present; the white fumes formed, too, combine with water to make an acid, as when the phosphorus burns in oxygen. In fact, all tests prove the products to be identical. Hence, in air also, the burning consists of the union of the burning substance with the oxygen of the air to form a new compound—*an oxide*.

It would be easy for the student to verify this by burning in air the different substances which were burnt in oxygen, and carefully comparing the products.

The air is not a chemical compound, but a mixture of gases.—In proof of this statement, the following facts and experiments may be cited:

1. The composition of a chemical compound never varies, while the composition of air does vary slightly.

2. Whenever a chemical compound is formed, a certain amount of heat is developed, and there is generally a change of volume. When, however, oxygen and nitrogen are mixed in the proportion in which they occur in the air, there is no evolution of heat nor change of bulk, though the mixture cannot be distinguished from air.

3. The proportion in which oxygen and nitrogen are mixed in the air does not bear any simple relation to the combining weights of these elements (p. 290), whereas in the case of every true chemical compound, the amounts of the constituent elements always bear some simple ratio to these weights.

4. When air is shaken up with water, some of it is dissolved. If air were a chemical compound it would be dissolved *as a whole*, and therefore the dissolved part would have the same composition as the undissolved part. But this is not found to be the case. The air dissolved in water can be expelled by heat, and if it is collected the oxygen in it is found to be more in proportion to the nitrogen than it is in ordinary air, thus showing that water dissolves more oxygen than nitrogen.

Ordinary air consists of about one-fifth oxygen and four-fifths nitrogen; but air expelled from water contains about one-third oxygen and two-thirds nitrogen.

5. When air is liquefied by intense cold and great pressure, and the liquid air is then permitted to evaporate, the nitrogen is first given off, so that the liquid becomes richer and richer in oxygen. If air were a compound, no one part of it would be more volatile than the other.

CHIEF POINTS OF CHAPTER XVI.

Rusting of iron.—Iron in rusting gains in mass, taking some material from the air, and this material is the part of the air concerned in burning and called oxygen.

Rust of iron.—Other compounds of iron and oxygen, besides that formed when iron rusts, are known. They are all called *oxides* of iron. *Specular iron ore*, *haematite*, and *lodestone* are all oxides of iron.

Nitrogen.—Nitrogen is the inactive part of the air. It makes up 80 per cent. (roughly) of the atmosphere. It is a very inert element. It neither burns nor allows things to burn in it. It is left behind when substances burn in air.

Oxygen.—Oxygen is the active part of the air. When red oxide of mercury is heated it decomposes into the elements mercury and oxygen. Oxygen can also be obtained by heating potassium chlorate, when potassium chloride, a substance very like common salt, is left behind.

Phosphorus.—Two varieties of this non-metallic element are known: *yellow* or *ordinary*, and *red* or *amorphous* phosphorus. Phosphorus must never be handled. Yellow phosphorus is kept under water. If heated to 250° C. in an atmosphere which does not act upon it, yellow is converted into red phosphorus.

Oxides.—When some elements are heated in oxygen they unite with it, forming *oxides*. Thus:

Iron and oxygen form oxide of iron.
Phosphorus and oxygen form oxide of phosphorus.
Carbon and oxygen form oxide of carbon.
Sodium and oxygen form oxide of sodium.

Some oxides unite with water to form *acids*, which turn blue litmus red; the oxide of phosphorus is an example.

Other oxides unite with water to form an *alkaline solution*, which has a soapy feel and the power of turning reddened litmus blue again; the oxide of sodium is an example.

EXERCISES ON CHAPTER XVI.

1. The inside of a glass bottle is moistened with water and well smeared with clean iron filings. The bottle is allowed to stand for a

day or two upside down and with its mouth under water. What changes will be found to take place (1) in the iron filings, and (2) in the air in the bottle? (P.T., 1898.)

2. What are the chief properties of oxygen?

Describe the experiments you would make to illustrate these properties. (1898.)

3. Oxygen and nitrogen are the two chief ingredients in common air. State reasons for the usual belief that they are not combined together chemically. (1897.)

4. Describe experiments which prove that air is composed of at least two gases.

5. How would you show by experiments that only one part of the air is concerned in (*a*) burning, (*b*) rusting?

6. Describe briefly the sequence of experiments which indicate the existence of oxygen in air, and give a mode of preparation of this gas.

7. How is oxygen most conveniently prepared? Give an account of its characteristic properties.

8. How can nitrogen be obtained from the air, and what are its chief properties?

9. Describe experiments which prove that during rusting and burning an increase of mass occurs.

10. By the combustion of different substances various oxides may be produced. Point out how by the action of water these oxides may be divided into two classes, and give examples.

CHAPTER XVII.

WATER AND HYDROGEN.

59. WATER.

i. **Action of heated iron on water.**—Place some iron filings in the hard glass tube *CA*, and let the end *A* dip under water. To the end *C* fit a delivery tube from a flask containing water previously boiled to drive off the dissolved air. Heat the iron filings well, and boil the water in the flask so that steam passes over the heated iron, and then into the water, where it condenses. Now place over the end *A* an inverted test-tube of water, and note that the steam is not

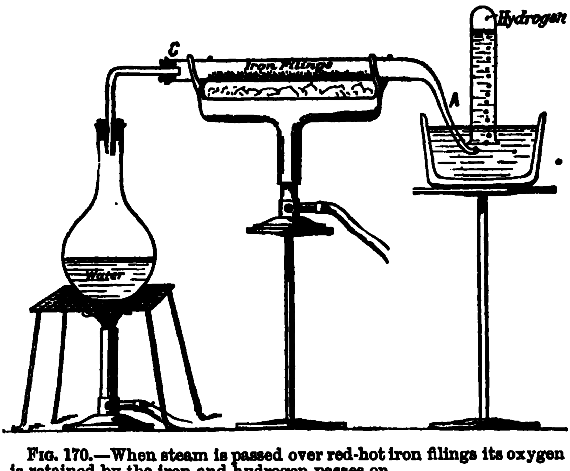

FIG. 170.—When steam is passed over red-hot iron filings its oxygen is retained by the iron and hydrogen passes on.

completely condensed, but that minute bubbles ascend to the top of the test-tube. When you have so obtained a sufficient quantity of gas (half a small test-tube), first disconnect *C* from the flask of water, then stop the boiling. Close the end of the test-tube with your

thumb, and holding a lighted match to the mouth, open the tube. Observe that the gas *burns*. Examine the iron filings in the tube *CA*, and see that a quantity of rust has been formed.

ii. **Action of sodium on water.**—Place a small piece of sodium* in water in an evaporating basin, and quickly put a large glass shade over the latter; observe the action. Feel the water left after the sodium has all disappeared, and test it with red litmus. Evaporate away the water. Note the residue.

iii. **Collection of the gas which sodium turns out of water.**—Place a small piece of sodium in a small piece of lead tubing, the ends of which are nearly closed, and gently drop the lead into a pan of water. A gas is seen to come off (Fig. 171). Collect this in an inverted tube full of water, and by this means obtain three test tubes of the gas. Observe that the gas is colourless and odourless.

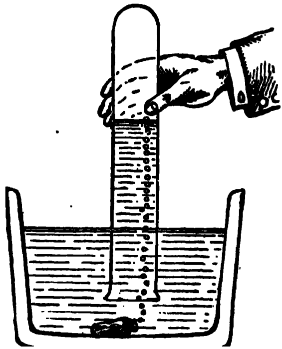

FIG. 171.—Sodium combines with the oxygen of water and turns out the hydrogen.

iv. **Examination of the gas produced by the action of sodium upon water.**—Take out two of the tubes and hold them for the same time, say, 30 seconds, (1) with mouth up, (2) with mouth down. Then apply a light to the mouth of both.

Now try the 3rd tube, holding it mouth down, and place a lighted match up into the tube. Note that the gas does *not* explode, but burns quietly, while the match is extinguished.

Chemical examination of water.—Before proceeding to study the chemical behaviour of water it will be well to recapitulate what has been already learnt about it. Water is a clear liquid with a blue-green colour, best seen by causing light to pass through a considerable length of it. It boils at 100° C., and is then converted into steam. It freezes at 0° C., becoming ice. Its density is 1, *i.e.* the mass of 1 c.c. is 1 gram at 4° C. and slightly less at any other temperature, owing to the fact that water expands when either cooled below or heated above 4° C. It has the power of dissolving many substances—*e.g.* salt, sugar, etc.—forming solutions from which the water

* Great care must be taken when using sodium, which must never be allowed to touch damp materials. It is kept under naphtha until used, and should never be handled with the fingers. It should be dried by blotting paper when taken from the bottle and cut with a clean knife, the pieces not used being immediately replaced in the bottle.

may be evaporated away, leaving the solid behind. But these facts tell nothing of the chemical nature of water, because changes in composition are not concerned. The water, present all the time, is not converted into any new product. By suitable experiments, however, the mutual action between water and some other substances may result in entirely different products. It has been seen that if iron is left in water it forms a considerable quantity of *rust*. But this may be due to the air which may be dissolved in water, for if the iron be placed in a tube containing water which has first been well boiled to drive off the air and the tube is then sealed in a blow-pipe, the iron either does not rust or does so to only a very slight extent.

If, however, the iron is heated and water is passed over it in the form of steam, in the manner described in Experiment 59. i., a chemical action begins which teaches several important facts about the composition of water. Not only do the iron filings become rusty, just as they do when exposed to damp air, but a gas, insoluble in water and which can be collected over a trough, as shown in Fig. 170, is obtained. This gas burns when a lighted taper is brought near it.

Action of sodium upon water.—It has been seen that from steam and iron it is possible to obtain iron rust, that is, iron oxide, and an inflammable gas. This fact suggests that water contains this inflammable gas as well as oxygen, and a way to test this is to find something which has a powerful chemical attraction for oxygen, for, if this substance is placed in contact with water, it will take up the oxygen and leave the other constituent of water. Such a substance is the metal sodium.

When a small piece of sodium is thrown upon water it swims about on the surface with a hissing noise; and the solution, after the sodium has all disappeared, has a soapy feel and turns red litmus blue. In this case we can only see that the action is energetic and a new product is formed, while the soapy feel of the water and its action on litmus appear to indicate that this product is the same as that obtained when sodium is burnt in oxygen and the fumes formed are dissolved in water. If the piece of sodium is enclosed in a piece of lead piping, the ends of which are flattened, the gas comes off in such a way that it can be collected with ease, and it is then observed to be colourless and to have no smell. If two tubes, which have been filled with the gas (Fig. 171) and held for thirty seconds, one with its

mouth upwards and the other with its mouth downwards, have a lighted match applied to them, it is found that there is no effect with the first tube and a slight explosion with the second.

The slight explosion of (2) shows it to contain an explosive gas, while the absence of any effect with (1) shows that the gas has all disappeared. Hence, it is seen that the gas escapes from a tube held mouth upwards, but not so quickly from one held mouth downwards. It is therefore lighter than air, being in fact the lightest gas known.

If a third tube of the gas is examined in the same way, immediately on taking it out of the water, the gas does not explode, but burns quietly.

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60. PREPARATION AND PROPERTIES OF HYDROGEN.

i. **Preparation of hydrogen.**—Select a flask and fit it up as is shown in Fig. 172. Be very careful that the stopper and the tubes respectively fit very closely. Into the flask put enough granulated zinc to

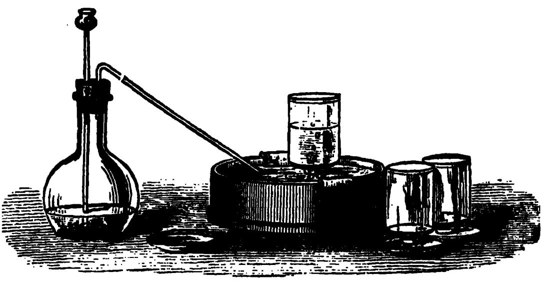

FIG. 172.—Zinc turns hydrogen out of dilute sulphuric acid.

cover the bottom. Pour some water upon the zinc. Arrange the delivery tube in the trough as you did when you were making oxygen. Pour a little sulphuric acid down the thistle-headed acid funnel, and be quite sure that the end of the funnel dips beneath the liquid in the flask. Do not collect bottles of the gas until you are sure pure hydrogen is being given off, which you can find out in this way. Fill a test-tube with water and invert it over the end of the delivery tube. When it is full of gas, still holding it upside down, take it to a flame (which should not be near the flask you are using); notice that there is a slight explosion. Continue this until the hydrogen burns quietly down the test-tube. When this happens you may proceed to fill one or two bottles. When the bottles have been filled, it is better not to remove them from the water until you

want to use them. Collect also a soda-water bottle half full of the gas.

Caution.—*Be careful not to bring a light near the thistle funnel or tube delivering the gas, even when the action in the flask seems to have ceased, or a dangerous explosion may occur.*

Be careful also that none of the acid used gets upon your fingers or clothing.

ii. **The liquid left in the flask.**—Filter off the liquid in the flask from the undissolved zinc (sufficient zinc should be used to leave a quantity still undissolved; if all has disappeared add more and wait till the action ceases). Partially evaporate the liquid and allow it to crystallise. You will find that a quantity of clear colourless crystals are formed. Examine them and sketch the most perfect. Heat some of the crystals in a tube and observe that they melt, give off water (which can be collected and proved to be water), and leave a white powder.

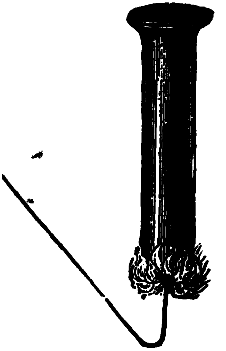

FIG. 173.—Hydrogen burns but extinguishes a flame.

iii. **Hydrogen burns but extinguishes a flame.**—Test one jar of the gas by means of a lighted match or taper. Observe that the gas burns at the mouth of the jar but that the taper is extinguished when thrust into the tube, but, on being taken out, again becomes alight on passing through the flame of the burning hydrogen (Fig. 173).

iv. **Hydrogen is lighter than air.**—Take a full jar of the gas and hold it mouth upwards below a second smaller jar held mouth downwards, as shown in Fig. 174. On testing with a lighted taper observe that the gas has left the lower jar and filled the upper. Many experiments, as the filling of balloons or soap bubbles, may also be performed to demonstrate the extremely low density of hydrogen.

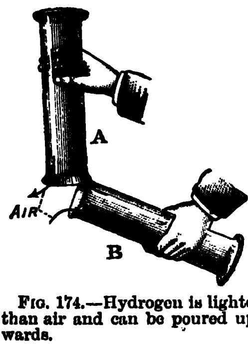

FIG. 174.—Hydrogen is lighter than air and can be poured upwards.

v. **Hydrogen forms an explosive mixture with air.**—Wrap your hand in a duster and with it hold the soda-water bottle. Take it out of the water so that the water runs out, and the bottle is now filled with a mixture of hydrogen and air. Apply a light and you will not fail to observe that an explosion results.

vi. **The flame of burning hydrogen.**—Fit a straight-pointed tube drawn out to a point to a hydrogen generator, as shown in Fig. 175. After pouring a little sulphuric acid down the thistle funnel, collect a test-tube of the gas issuing

from the straight tube, and hold the mouth of the test-tube near a flame, *which must be a few feet away from the generator.* The gas will at first go off with a pop, or burn with a squeaking noise, but after two or three trials it will burn quietly, with a blue flame. *When you can carry this flame of burning hydrogen to the apparatus from which the gas is being produced, do so, and use it to ignite the gas escaping from the pointed tube.* If you remember always to do this, there can be no danger,

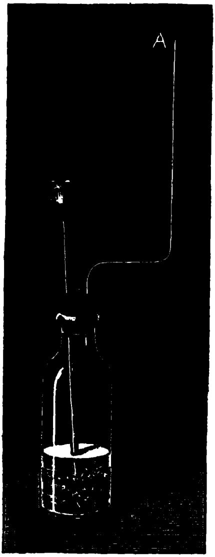

FIG. 175.—Arrangement for obtaining a flame of hydrogen.

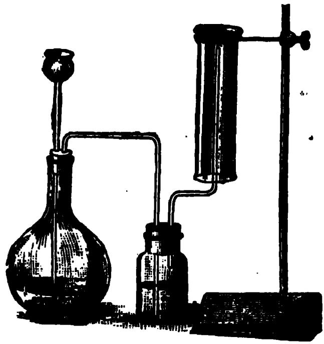

FIG. 176.—Hydrogen being lighter than air can be collected by upward displacement.

for when you are able to carry a flame of hydrogen in a test-tube of the gas, for a distance of two or three feet to the generating apparatus, you may be sure that the hydrogen issuing from the apparatus is not mixed with air.

Light the hydrogen in this way.

Observe that it burns with a pale blue flame, which after a time becomes yellow. This coloration is due to the glass becoming hot, and some of the substances in it being burnt in the flame of hydrogen.

vii. **Hydrogen can be collected by upward displacement.**—Substitute for the delivery tube in Expt. 60. i. a tube bent twice at right angles, as shown in Fig. 176, and arrange a jar on a retort-stand in an inverted position. Place a test-tube over the upright tube, and allow it to stay there for a minute, and test the gas as described in Expt. 60. vi. When it is pure, substitute the inverted jar, and after a few minutes lift it off the stand and apply a light, first taking the precaution to wrap a duster round the jar and to hold it away from your face. The jar will be found to contain hydrogen.

Preparation of hydrogen in large quantities.—It has been seen that from water and sodium it is possible to obtain an

inflammable gas, lighter than air, which does not support combustion; and a solution which behaves like the solution of sodium oxide is also formed. The most natural inference is that the water contains this inflammable gas, which is called *hydrogen*, combined with oxygen. Before proceeding to verify this, it will be well to examine more carefully the properties of the inflammable gas, and to do this it is necessary to collect the gas in greater quantity than hitherto. For this purpose we must act with a metal, such as zinc, upon a dilute acid, say sulphuric acid, instead of water.

The apparatus suitable for the preparation of hydrogen in this way is described in the experimental work (p. 231). Owing to the insolubility of hydrogen in water, it can be collected in the same way as oxygen over the pneumatic trough. If when the chemical action in the flask has completely stopped, the liquid is filtered from the still undissolved zinc, as previously explained, and then partially evaporated in a basin and afterwards allowed to crystallise, a quantity of clear colourless crystals are formed. These crystals melt if heated in a tube, give off water, and leave a white powder. These crystals are a compound formed from the zinc and part of the sulphuric acid, and are known as *zinc sulphate*.

We may therefore state *sulphuric acid and zinc form hydrogen and zinc sulphate.* Or, the same fact may be expressed in another way:

SULPHURIC ACID	when acted upon with	ZINC gives	ZINC SULPHATE	and	HYDROGEN.

Water of crystallisation.—Many crystals behave like zinc sulphate on being heated, *i.e.* they lose water which they previously contained, and become converted into a powder. The water contained in a crystal and evolved on heating is known as *water of crystallisation.* Some substances, like blue vitriol (copper sulphate), change in colour when their water of crystallisation is driven out by heat. But the colour can be regained by adding water.

Properties of hydrogen.—Having now a means of obtaining hydrogen in considerable quantity it can be observed that it is a colourless, odourless gas, considerably lighter than air; it burns, but does not support combustion, and it forms a highly

explosive mixture when mixed with air. It is now necessary to obtain and examine the compound which is produced by the burning of hydrogen, that is, the oxide of hydrogen.

61. WHEN HYDROGEN BURNS WATER IS FORMED.

i. **Water is formed by burning hydrogen.**—(*a*) Arrange a flask as before for the production of hydrogen. Pass the gas through a tube containing chloride of calcium in order to thoroughly dry it. Allow it to burn under a retort which is kept cool by a stream of water flowing in at the tubule and out at the end of the neck (Fig. 177).

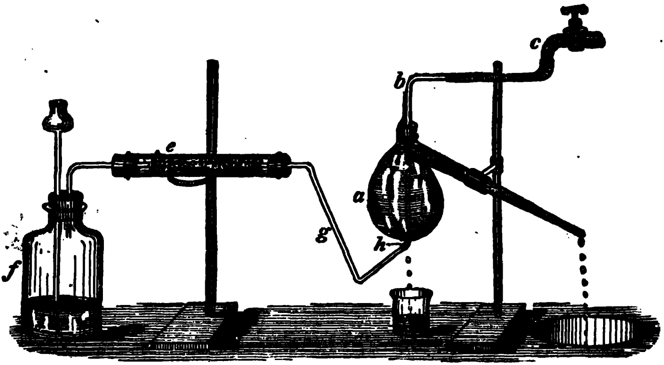

FIG. 177.—The water formed when hydrogen burns in air can be collected and examined.

Observe the formation, on the outside of the retort, of a clear liquid which collects and drops into a beaker placed to receive it. By this means sufficient of the liquid can be obtained to identify it, especially if several students add together the liquids formed in their experiments.

(*b*) Take the density, freezing point (a mixture of sodium sulphate and hydrochloric acid forms a very convenient freezing mixture), and boiling point of the liquid formed by burning hydrogen. You will find these are 1, 0° C., and 100° C. respectively, and these results are sufficient to enable us to state that the liquid is identical with pure water.

ii. **Analysis of water.**—This may be done by means of an electric battery for generating the electric current, and a *voltameter*. The latter is most simply made by closing the bottom of a funnel by means of a tightly-fitting cork through which pass two platinum wires with small plates of platinum attached to the ends remaining

in the funnel (Fig. 178). Over these plates are supported two glass test-tubes of equal capacity, and the tubes and part of the funnel are filled with water to which has been added a little sulphuric acid, as otherwise it offers great resistance to the electric current. The wires from a battery of three or four cells are connected with the ends of the platinum wires, and as soon as the connection with the battery is complete, provided there is clean metal at every junction, bubbles of gas are seen to rise from each platinum plate, and to ascend into the tube and displace the contained liquid. After the experiment has gone on for half an hour, the gases may be tested and their volumes measured. It will be found that the volume of one gas is double that of the other, and that the gas of which there is the larger amount is *hydrogen*, while the other is *oxygen*.

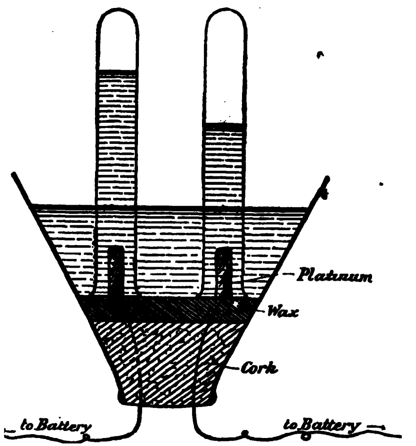

FIG. 178.—A voltameter in which water can be analysed by the electric current.

Formation of water by burning hydrogen.—When a jet of burning hydrogen is brought in contact with a cold surface, such as a cold glass, the product of combustion, or the oxide of hydrogen, is condensed. If after a sufficient quantity of the liquid has been collected it is examined, it is found (*a*) to have a density of 1, (*b*) to freeze at 0° C., and (*c*) to boil at 100° C. These are the physical characteristics of water and of no other substance, so we are justified in stating that this liquid, formed when hydrogen burns, is water.

Previous experiments have indicated that water contains hydrogen and oxygen, so that it can now be said that: *Hydrogen in burning produces water, which is, therefore, an oxide of hydrogen.*

Proportions of oxygen and hydrogen in water.—The proportions in which the oxygen and hydrogen combine during the formation of water must now be considered. This may be

done in either of two ways, viz., by finding the mass of the gases, or by finding the volume of the gases, which combine. For the latter purpose it is necessary to measure out definite volumes of oxygen and hydrogen, cause them to combine, then measure the volume of gas which remains uncombined and ascertain which gas it is. This is usually done in a piece of apparatus known as an *Eudiometer* (Fig. 179). In its simplest form this consists of a long glass tube closed at one end and graduated in equal volumes, usually cubic centimetres, by divisions marked on the glass. Through opposite sides of the tube, at the closed end, pieces of platinum wire are passed and fused into the glass, being so arranged that they do not quite touch one another. Outside the tube the platinum wires are bent into loops to which wires from an electric coil may be attached so that an electric spark can be passed between the ends of the platinum wires inside the tube to explode the mixed gases. Using an instrument of this kind, it can be proved that 2 *volumes of hydrogen combine with* 1 *volume of oxygen to form water*.

FIG. 179.—A simple form of eudiometer. The arrangement of the platinum wires is shown in the enlarged top of the eudiometer.

Such a process as this, the formation, that is, of a compound from its elements, or from simpler materials, is known as a *synthesis*.

The required ratio may also be found by the *analysis* of water, that is, by breaking the liquid up into its components, which can be done by passing an electric current through it.

This experiment again proves what was found by synthesis, viz., that 2 volumes of hydrogen combine with 1 volume of oxygen, and further, it may be noticed that both experiments also prove that water is solely formed from these two gases, and contains no other constituent.

62. COMPOSITION OF WATER BY MASS.

i. Action of hydrogen on heated copper oxide.—Arrange an apparatus like that shown in Fig. 180, in which a flask *A* for the

making of hydrogen is connected with the bottle *B* containing strong sulphuric acid. The passage of the hydrogen through the strong

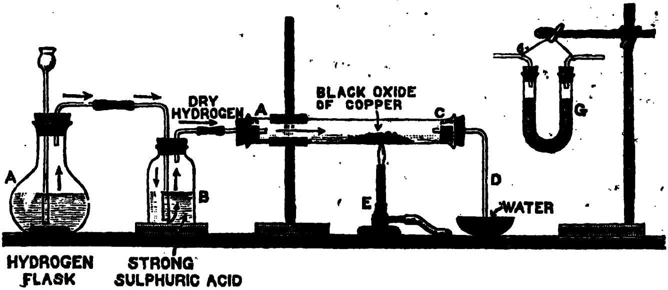

FIG. 180.—When hydrogen is passed over heated oxide of copper it extracts the oxygen, with which it forms water, and leaves copper behind.

acid completely dries the gas. A small amount of the black oxide of copper is placed in the hard glass tube *AC*, which is about 1·5 centimetres in diameter, and fitted with the tube *D* in the manner shown. When you are sure that pure dry hydrogen is escaping from the open end of *D*, heat the oxide of copper in the tube by means of the burner *E*. In a few minutes moisture will be seen to collect in the tube *D*, and presently to drop into the dish put to collect it.

Examine the residue in the hard glass tube, and note its change to a reddish colour; this is due to the presence of copper.

Rearrange the apparatus, using the U-tube *G* in the place of the tube *D*. The U-tube *G* containing lumps of calcium chloride is employed to collect the water formed.

ii. **Composition of water.**—Put some copper oxide into the tube *AC*, and carefully weigh the tube. Similarly, the mass of the U-tube *G* and its contents must also be determined by weighing. As in the last experiment, when you are sure pure dry hydrogen is escaping from the open end of *G*, heat the copper oxide by means of the laboratory burner. Be sure that all the water formed is collected by the U-tube. If any condenses at the end of the hard glass tube *AC*, drive it over by heating the tube at this place.

Allow the tube *AC* to cool. Disconnect it at *A* and *C*, and again determine its mass and that of its contents by weighing. Notice the diminution in mass. Also weigh the U-tube again, and observe its increase in mass.

Relative masses of the constituents of water.—To find the composition of water by mass, that is, the masses of oxygen and hydrogen which combine to form water, it should be noticed that we only require the masses of two out of the three substances concerned, *i.e.* if we know the masses of hydro-

gen and water (or of oxygen and water), the mass of the oxygen (or hydrogen) is readily calculated. The experiment is done by finding the masses of the oxygen and water, and for this it is best to use not oxygen itself, but some oxide which readily gives up its oxygen to the hydrogen, so that by weighing the oxide before and after the experiment we can ascertain the mass of oxygen which it has lost. The oxide used for this purpose is usually oxide of copper, a black powder, which it has been seen is obtained when air is passed over red hot copper. Pure dry hydrogen is passed over the heated oxide, and it combines with the oxygen of the oxide to form water and leaves the copper behind.

By weighing the water produced and subtracting from it the mass of the oxygen used, the mass of the hydrogen can be found. If the experiment is carefully performed it is found that *water is formed of eight-ninths its mass of oxygen with one-ninth its mass of hydrogen.*

This experiment, also taken in conjunction with other experiments upon the volumes of the gases proves further that one volume of oxygen is 16 times as heavy as the same volume of hydrogen. One litre of hydrogen weighs nearly ·09 gram (accurately ·0896).

63. SOLVENT POWERS OF WATER.

i. **Solution.**—(*a*) Place a piece of sugar in water, and note that it soon disappears, and gives a sweet taste to the whole of the water, so that the particles of the sugar must be spread through the entire mass of the water.

(*b*) Weigh out 50 grams of each of the following substances: Finely powdered nitre, sugar, salt, and to each add water, in small quantities, with vigorous shaking after each addition. Determine thus the quantity of water necessary to form a saturated solution of each.

(*c*) Weigh out an ounce each of sugar, common salt, and powdered gypsum. By increasing the amount of water ascertain how much is necessary to completely dissolve each of the powders. Show the amounts of water are roughly 1 ounce, 3 ounces, and 360 ounces (2¼ gallons) respectively.

ii. **Solution is a physical change.**—(*a*) Weigh out a quantity of salt in an evaporating basin and dissolve it in water. Heat gently over a Bunsen burner, so that the water boils and evaporates away completely. Note that a white solid remains in the basin, and again weigh. Satisfy yourself that the mass is equal to the mass of the basin and salt before solution, and that the solid left is still salt.

(*b*) Evaporate a little distilled water in a platinum or porcelain crucible. Notice the absence of any residue. Repeat the experiment with tap water, and note the residue.

iii. **Effect of temperature on solution.**—Place a quantity of powdered nitre in water, and after frequent vigorous shaking, allow it to stand for some time so that a cold saturated solution is formed. Now heat the solution and see whether more solid dissolves or not.

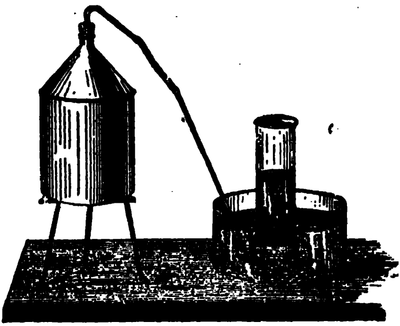

FIG. 181.—Apparatus to show that ordinary water has air dissolved in it.

iv. **Gases dissolve in water.**—Completely fill a gallon tin can with tap water, and attach a cork and delivery tube, dipping under a jar of water inverted in a trough (Fig. 181). Heat the can and observe that dissolved air is driven out. Collect the air and see that, since it supports combustion, it contains oxygen.

Water as a solvent.—If a piece of sugar is put into water it soon disappears, and the liquid is found to be sweet in every part. The sugar has *dissolved* to form a *solution* of sugar. Similarly, a very great number of substances dissolve in water, but not all to the same extent. Those substances which dissolve in this manner are called *soluble*, while those which do not are spoken of as *insoluble*.

Water dissolves a larger number of things than any other liquid. This explains why we cannot find pure water in nature. No sooner does rain form than it begins to dissolve various substances; in its passage through the air it takes up varying amounts of the constituents of the atmosphere, such as carbon dioxide and oxygen; and when the surface of the earth is reached the water dissolves out of the soil and the underlying rocks portions of all the soluble ingredients. The more soluble bodies are naturally dissolved to the largest extent. It will be seen later that the solvent property of water is considerably increased by the presence of carbon dioxide which it obtains in part from the air. When the amount of material dissolved in water is very great, it gives a distinctive character to the liquid, which becomes known as a *mineral water*. Those natural waters

which contain a compound of sulphur and hydrogen, called sulphuretted hydrogen, are spoken of as *sulphur* waters; if some compound of iron is the substance which has been taken up in large quantities, we have *chalybeate* waters formed. *Effervescent* waters have a great amount of dissolved carbon dioxide.

Hard and soft waters.—It is a fact familiar to every one that soap lathers very easily in some waters and not at all in others. If rain-water be used, the lathering takes place with great ease, while with the water which is supplied to some towns a lather can only be made with difficulty; and if we attempt the same process in sea-water there is no lathering at all. *Those waters in which soap lathers easily are said to be soft. When this is not the case the water is spoken of as hard.* The explanation is a simple one. Water dissolves materials out of the rocks below the soil, and often takes up, among other things, compounds of calcium and magnesium, which unite with soap forming a new compound of an insoluble kind; and, in consequence, there is no lathering until all the calcium and magnesium have thus combined with soap, after which the solution or lathering of the soap begins. The soap which combines with the dissolved materials is, of course, wasted.

Temporary and permanent hardness.—Hard waters differ among themselves. Some can be softened by mere boiling, and when this is the case the hardness is said to be *temporary*. If the hardness is not removed after the water has been boiled, and the water requires the addition of a chemical to soften it, such hardness is termed *permanent*. As has already been mentioned, the presence of carbon dioxide in water gives it the power of dissolving substances which would be otherwise insoluble. Chalk, known to chemists as calcium carbonate, is insoluble in pure water, but in water in which there is carbon dioxide it dissolves to a considerable extent. As soon as this dissolved gas is got rid of, which can be done by boiling, the chalk, being no longer soluble, is thrown down upon the sides of the vessel. It forms in this way the incrustation which is found on the inside of kettles and boilers.

Permanent hardness is due to the presence of dissolved calcium sulphate and other compounds. Since these substances are soluble in pure water, mere boiling will not get rid of them. Washing soda, which is a form of sodium carbonate, softens such

water as this, by causing the formation of calcium carbonate in the place of the calcium sulphate.

Distillation of water.—If the steam which is formed by boiling water containing any dissolved substances be condensed, the water formed is quite pure. To obtain pure water from any kind of water, then, whether fresh or salt, all that has to be done is to boil it and condense the steam which is given off. The dissolved materials are all left behind in the vessel in which the boiling takes place. An arrangement for condensing steam or vapour is shown in Fig. 182. The steam

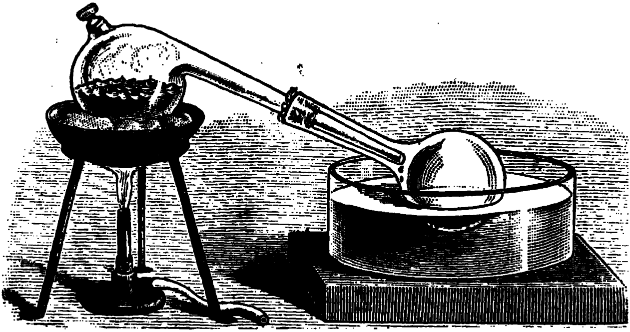

FIG. 182.—A simple arrangement for distilling water.

driven off from the water in the retort passes into a flask kept cool by resting upon a basin of cold water, and is thus condensed. It is advisable to place a wet duster, or a wet piece of blotting paper, upon the flask to assist the condensation.

CHIEF POINTS OF CHAPTER XVII.

Water is a clear liquid with a blue-green colour. It boils at 100° C., when it is converted into steam. It freezes at 0° C., becoming ice. Its density at 4° C. is 1. It possesses great solvent power.

Hydrogen is contained in water.—This fact has been proved by causing heated iron to drive hydrogen out of the water, when the iron combines with the oxygen which is left to form oxide of iron.

Sodium turns the hydrogen out of water at ordinary temperatures. The hydrogen can be collected and examined.

Preparation of hydrogen.—Hydrogen is best prepared by acting upon a dilute acid with a metal. Sulphuric acid and zinc have been found to be suitable.

Sulphuric acid and zinc form hydrogen and zinc sulphate.

Properties of hydrogen.—It is a colourless, odourless gas, considerably lighter than air. It does not support combustion, but

itself burns in air. It forms an explosive mixture when mixed with air.

Production of oxide of hydrogen.—By collecting the product of combustion when hydrogen is burnt, and examining it, it is found to be a clear liquid with density 1, boiling point 100° C., freezing point 0° C. The product, or oxide of hydrogen, is thus seen to be really water. *Hydrogen in burning produces water, which is, therefore, an oxide of hydrogen.*

Composition of water by volume.—This can be determined by means of an *eudiometer*. *Two volumes of hydrogen combine with one volume of oxygen to form water.* This process of building up a compound from its elements is called *synthesis*.

The opposite process of splitting a compound up into its elements is called *analysis*. The analysis of water is effected by passing an electric current through water contained in a *voltameter*. The result of such an experiment is precisely the same as that obtained by synthesis with the eudiometer.

Composition of water by mass.—Pure dry hydrogen is passed over heated oxide of copper. The hydrogen combines with the oxygen of the oxide, forming water, and leaves the metallic copper behind. The water formed is collected and weighed. The copper oxide is weighed before and after the experiment. Its loss in mass tells us the amount of oxygen in the water formed. The difference between the mass of the water formed and the oxygen it contains tells us the mass of the hydrogen in the water. When carefully performed, the experiment shows that *water is formed of eight-ninths its mass of oxygen and one-ninth its mass of hydrogen.*

Natural waters generally contain dissolved materials. When the amount is very large the water is called a *mineral water*. Natural waters containing sulphuretted hydrogen are called *sulphur* waters; those containing compounds of iron are called *chalybeate* waters; and those containing much carbon dioxide are spoken of as *effervescent.*

Hard and soft waters.—Those waters in which soap lathers easily are said to be *soft*. When such is not the case the water is spoken of as *hard*. Hard waters which can be softened by boiling are said to have *temporary* hardness. If the water cannot be thus softened, but requires the addition of a chemical, its hardness is said to be *permanent*.

EXERCISES ON CHAPTER XVII.

1. Write down what you consider to be the physical and chemical characteristics of water, that is, the features and properties which are possessed by water, but by no other substance. (P.T., 1897.)

2. Describe a chemical method of liberating hydrogen from water (*a*) at a red heat; (*b*) at ordinary temperatures.

If you were provided with three bottles of hydrogen, what experiments would you perform to illustrate important properties of the gas? (P.T., 1897.)

3. How can you prepare hydrogen? How would you exhibit its properties to a class? What substance is produced when hydrogen is burnt? (P.T., 1898.)

4. A jar of oxygen, a jar of nitrogen, and a jar of hydrogen are put before you. How can you tell which is which? (P.T., 1898.)

5. Describe experiments (1) to show that water may be split up into oxygen and hydrogen, and (2) to show that by the combination of these gases water is produced. (1898.)

6. Describe experiments to show that water dissolves (1) air, (2) lime. (1898.)

7. Describe some important chemical changes in which water takes the principal part. (1897.)

8. Give examples of the solvent power of water. How could you determine whether a sample of water contained dissolved solid matter?

Describe the apparatus you would employ to obtain water free from dissolved substances. (1897.)

9. A current of steam is passed through a tube which contains pieces of iron heated to redness. What chemical change goes on within the tube, and what tests would you apply to identify the gas which escapes from the end of the tube? (1898.)

10. What is the difference between fresh water and sea water?

Describe, giving a sketch of the apparatus employed, a method of preparing drinkable water from sea water. (1898.)

11. Describe the apparatus you would use for the production and collection of hydrogen gas; name the materials required, and describe the properties of the gas. (1897.)

12. Describe three different methods by which hydrogen may be obtained from water.

How would you prove that air contains one of the constituents of water? (1897.)

13. What are the chief impurities in common water? How would you obtain pure water? Make a sketch of the necessary apparatus and explain the use of its several parts. (1897.)

14. What chemical reaction takes place when a small piece of metallic sodium is thrown into water?

How would you test whether the solution left is acid or alkaline, and how would you prepare from it some common salt in the crystalline state? (1899.)

15. Enumerate the differences in physical properties exhibited by sea and fresh water respectively. How can a specimen of common salt be prepared from sea water? (London Matric., 1900.)

16. Blue vitriol heated over a lamp becomes white; on being treated with water the blue colour is restored. Explain the reason of these changes. (1900, Day.)

17. Mention two methods of obtaining hydrogen from water. How would you recognise the gas when obtained? (Queen's Sch., 1899.)

CHAPTER XVIII.

CARBON AND SOME OF ITS COMPOUNDS.

64. FORMS OF CARBON.

i. **Carbon is contained in organic substances.**—Heat a series of organic substances, such as meat, wood, potato, egg, etc., in a crucible, and notice in all cases the production of a black residue, consisting largely of carbon. Heat more strongly, and observe that it burns away, leaving an almost colourless ash.

ii. **Properties of carbon.**—Examine and write down the properties of as many of the following forms of carbon as you can obtain:—diamond, blacklead, wood-charcoal, bone-black, and soot.

iii. **Charcoal is porous.**—(*a*) Show that charcoal floats in cold water. In boiling water charcoal sinks after a time, and then will not float again unless thoroughly dried. This is because air is driven out of the charcoal by the warmth of the water.

(*b*) Fill a large test-tube with ammonia gas* over mercury, and show that it can be absorbed by introducing a small lump of charcoal. This is a striking proof of the porosity of carbon.

Forms of carbon.—Carbon is an element which is very widely distributed in nature, being present in all living matter, and in most products resulting from vital activity.

Carbon occurs, combined with other elements, in many rock masses, being a constituent of all the minerals known as carbonates. Combined with oxygen as carbon dioxide, it occurs in the atmosphere and certain natural gases, or dissolved in spring waters.

Diamond.—In the pure state carbon exists in various allotropic forms (p. 275). Of these the purest and the most valuable is the *diamond*. This form of carbon is crystalline and very

* Ammonia gas can be easily prepared by heating an ordinary strong solution of ammonia in water (ammonium hydrate). The gas should be dried by passing it upwards through a cylinder containing dry quicklime. It can be collected over mercury in a trough.

hard, being capable of scratching all other materials. Its refractive index (p. 171) is very high, and on this depends its brilliancy as a gem. Diamond is proved to consist of carbon by burning it in air or oxygen, when only *carbon dioxide* results.

Blacklead or **graphite** is another form of almost pure carbon, with properties totally different from those of the diamond. It is opaque and black, and so soft that it will mark paper. It is really a crystalline form of carbon, although good crystals are not very common. It occurs naturally in mines, chiefly in California, and was formerly largely obtained from Cumberland. Besides its use for lead pencils, it is also used as a lubricant.

Amorphous varieties.—Other forms of more or less pure carbon in an *uncrystallised* or *amorphous* state are *coke*, and *gas carbon*, which result from the heating of coal; *lampblack*, which is the carbon deposited by oils, etc., burning in an insufficient supply of oxygen; *wood charcoal*, obtained by heating wood in closed retorts or in stacks under earth.

Charcoal has the power of absorbing many gases, and also of absorbing colouring matter, and on the latter account it is used for decolorising solutions coloured by organic matter. *Animal charcoal* is really a misleading term, as the quantity of carbon present is usually only about 10 or 12 per cent., the remainder being chiefly bone ash.

Both animal and wood charcoal are very porous substances, and they have the power of absorbing gases to a large extent. Wood charcoal is used considerably on the Continent for heating purposes. Both kinds are useful in destroying noxious vapours.

Coal contains large quantities of carbon, especially the harder or anthracite coals, where the quantity may reach 94 per cent., being, however, only about 65 in brown coal or lignite.

Whenever any of the kinds of carbon burn in air or oxygen, carbon dioxide is the compound formed, thus affording evidence that the three varieties are only allotropic forms of a single element carbon.

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65. CARBON DIOXIDE PRODUCED BY BURNING AND BREATHING.

i. When carbon is burnt carbon dioxide is formed.—(*a*) Heat strongly a piece of charcoal in a closed hard glass test-tube and show that without air it does not burn.

(*b*) Suspend a piece of glowing charcoal in a bottle containing lime-water. Shake up and show that the lime-water is turned milky. Carbon dioxide can always be distinguished by this action upon lime-water, for it is the only common, colourless, inodorous gas which turns lime-water milky.

ii. **Carbon dioxide is produced by a burning candle.**—(*a*) Burn a candle or taper in a clean dry white bottle (Fig. 167). After the flame has been extinguished, withdraw the taper. Pour a little freshly made lime-water into the bottle and shake it up. Notice the milkiness of the lime-water.

(*b*) Cut a long thin chip of wood, hold it in the flame of a laboratory burner until it burns brightly, then thrust it into a cylinder or bottle, the bottom of which is covered with lime-water to the depth of about an inch. When the stick ceases to burn, withdraw it and shake the lime-water.

iii. **Carbon dioxide produced by breathing.**—(*a*) Blow through a piece of glass tube into some clear, freshly-made lime-water contained

FIG. 183.—The air breathed out from the lungs contains carbon dioxide, and will turn clear lime-water milky.

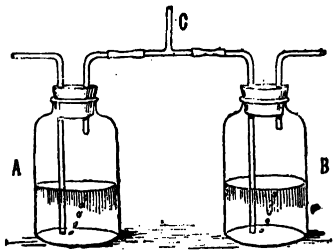

FIG. 184.—Air drawn into *A* does not turn the lime-water milky; but when blown through *B* from the lungs the lime-water in *B* is turned milky.

in a wine-glass or tumbler. Milkiness is at first produced, but if the blowing is continued long enough it by and by disappears.

Fill a jar with water and invert it in a basin of water. Blow air from your lungs into the jar by means of a tube. When the jar is full of air place a glass plate under it and lift it out of the water. Show that the air will extinguish a lighted taper.

(*b*) Repeat the two preceding experiments by blowing air from a bellows instead of from the lungs. Notice that this unbreathed air has not the same effects upon a lighted taper or lime-water as breathed air.

iv. **The air contains carbon dioxide.**—Pour some clear lime-water into a blue dinner plate, or some other shallow vessel of a dark colour. Leave it exposed to the atmosphere for a little while. Notice the thin white scum formed on the top. The carbon dioxide in the air has turned the top layer of liquid milky.

v. **Breathing changes the character of air.**—Fit two bottles with corks and tubes as shown in Fig. 184. See that the corks are air-

tight. Put some clear lime-water into each bottle. Place the tube *C*, or an india-rubber tube leading from it, in your mouth. When you suck at the tube, air is drawn in through the glass tube which dips into the lime-water in the bottle *A*. When, however, you blow instead of sucking, your breath passes out through the tube which dips into the lime-water in the bottle *B*. Notice that the lime-water in *A* remains clear, but that in *B* is rendered milky by the air you breathe out. You thus see that fresh air has little effect upon lime-water, but breathed air quickly turns clear lime-water milky.

vi. **Oxygen from plants.**—Take a bunch of fresh watercress, or water weeds, and put it into a beaker or glass jar very nearly filled with water saturated with carbon dioxide. Cover the plants with a funnel nearly as wide as the jar, as shown in Fig. 185. Fill a test-tube with water and invert over the funnel. If properly managed there should at first be no gas in the test-tube. Place the jar in bright sunlight for an hour or two and then examine it. You will notice bubbles of a gas have collected at the top of the tube. Test the gas with a glowing splinter of wood. It is found to be oxygen.

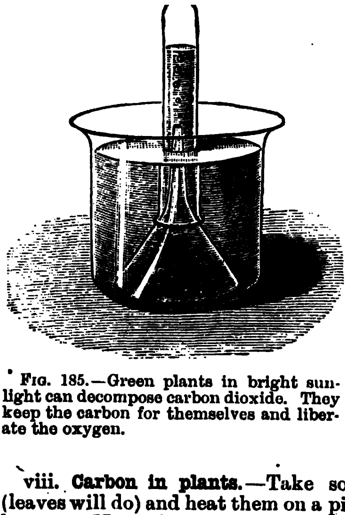

FIG. 185.—Green plants in bright sunlight can decompose carbon dioxide. They keep the carbon for themselves and liberate the oxygen.

vii. **Plants in sunlight and in darkness.**—Repeat the whole experiment, but instead of putting the bottle in bright sunlight place it in the dark. Observe that in such circumstances no bubbles of oxygen are formed.

viii. **Carbon in plants.**—Take some green portions of a plant (leaves will do) and heat them on a piece of tin plate over a laboratory burner. Note that they become charred, showing the presence of carbon in them.

Production of carbon dioxide by burning.—When things such as candles, oil, gas, and wood are burnt either in the air or in pure oxygen, a gas is produced which has the power of turning lime-water milky. All these substances contain, in one form or another, a substance called carbon. As you have seen in previous chapters, the gas produced when these substances burn is carbon dioxide, that is, the gas produced by burning carbon in air or oxygen. In fact, whenever a substance rich

in carbon burns in a plentiful supply of air or oxygen, this carbon dioxide is produced. Knowing how many fires there are in houses, furnaces, engines, and so on, it is not difficult to understand that at every hour of the day very large quantities of this carbon dioxide are formed, which escapes, sooner or later, into the air.

Carbon dioxide is given off in breathing.—If a person blows with the mouth into clear lime-water the lime-water is turned milky. This is another important fact. It is clear that carbon dioxide escapes from our mouths in breathing. And so it does from every animal. Not only, then, do all cases of ordinary burning result in the addition of carbon dioxide to the air, but also every act of breathing. It does not matter how small an animal is, all the time it is alive it is continually adding to the atmosphere a certain amount of the colourless, odourless gas which puts out flames and turns lime-water milky.

Purifying action of plants.—That there is always a certain amount of carbon dioxide in the air can be proved by exposing fresh lime-water in a shallow vessel. Very soon the lime-water becomes covered with a thin white layer of chalk, which is formed by the combination of the carbon dioxide in the air with the lime in the lime-water. One reason why there is never very much carbon dioxide in the air out of doors is because there is an agency continuously at work getting rid of this gas. This agency is the green parts of plants which occur everywhere.

When fresh watercress is put into a bottle completely full of water containing carbon dioxide in solution, and the bottle is inverted in a basin of water without allowing air to get into the bottle, it is found that, when the bottle and its contents are exposed to bright sunlight, bubbles of gas collect at the top of the bottle. These bubbles, when tested, are found to be pure oxygen. If, however, the bottle with the cress in it is kept in the dark no bubbles of oxygen collect. Or, if a bottle of water in which carbon dioxide is dissolved be put in sunlight, without any watercress, no oxygen collects in the top of the bottle.

In other words, two things are necessary for the formation of the bubbles of oxygen collected from the green plant as described.. They are (1) the vegetation, (2) the sunlight. The same conditions have been found to always hold true, thus proving that *green plants in the presence of bright sunlight have the power of turning oxygen out of carbon dioxide.* They keep

the carbon for themselves, and it helps them to grow. If the experiment were carefully performed it would be found that the watercress had increased in mass after being exposed in these circumstances to bright sunlight for some time.

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66. PRODUCTION OF CARBON DIOXIDE FROM CHALK BY THE ACTION OF AN ACID.

i. **Preparation of carbon dioxide.**—Into a flask or bottle, fitted like that in Fig. 186, place some chalk, or small pieces of marble. Place the delivery tube in a glass cylinder, or a jar with a wide mouth. A disc of cardboard, through which the delivery tube passes rests on the top of the jar. Pour dilute hydrochloric acid down the funnel. During the effervescence a gas is given off and collects in the jar. When a burning taper is extinguished immediately it enters the jar, take out the delivery tube and put it into another jar. Cover the first jar of gas with a disc of card. In the same way collect several jars of the gas.

ii. **Properties of carbon dioxide.**—(*a*) Notice that the gas is (1) invisible, without taste or smell; (2) that it extinguishes a lighted taper; (3) that it must be heavier than air or it could not be collected in the way described.

(*b*) Pour the gas from one jar (*B*) into another (*A*), as shown in the diagram (Fig. 187), and test both jars by a lighted taper. It will be seen that the lower jar contains the gas.

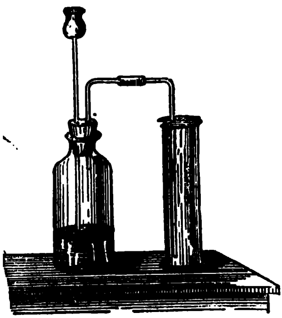

Fig. 186.—Apparatus for preparation and collection of carbon dioxide.

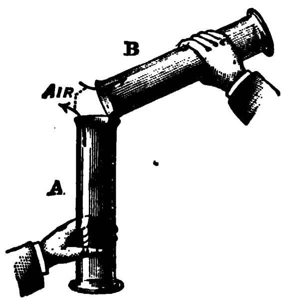

Fig. 187.—Carbon dioxide gas is heavier than air, and can therefore be poured from *B* into *A*, like a liquid.

iii. **Acid solution formed by carbon dioxide.**—Pour a little water made blue with litmus into a jar of the gas and shake it up. Some of the gas dissolves, and the colour of the solution turns red. Boil

the solution; the carbon dioxide is driven off, and the blue colour is regained.

iv. **Action of carbon dioxide on lime-water.**—Pass the gas from the delivery tube through some lime-water. Observe that a milkiness is produced, owing to the production of a white powder or *precipitate*, which disappears after a short time.

Boil the solution thus obtained, and notice that the milkiness again appears.

Filter the milky solution, and so obtain the white powder on a filter paper. Add a few drops of dilute hydrochloric acid to the powder. Notice the effervescence. Test the gas which is given off; it puts out a flame.

Preparation of bottles of carbon dioxide.—Though carbon dioxide is produced naturally by burning and breathing, and it also escapes from the earth in some regions, there are more convenient ways of obtaining the gas. Experiments show that when an acid is added to chalk, marble, or limestone, a gas is given off which puts out flames, turns clear lime-water milky, and possesses all the properties of carbon dioxide—it is, in fact, carbon dioxide. The best way to prepare bottles or jars of the gas is to place pieces of chalk or marble about the size of peas into a bottle fitted like that in Fig. 186. Dilute hydrochloric acid is poured down the thistle funnel, and when it comes into contact with the marble, the gas is given off. Enough acid is poured in to cover the bottom of the funnel, so the gas cannot escape up the funnel; and it passes through the other tube in the cork. The gas given off is heavier than air, and can therefore be collected as shown in Fig. 186. As the gas accumulates in the jar, the air is pushed out at the top. After several bottles or jars have been filled, the properties of the gas can easily be examined.

Properties of carbon dioxide.—An examination of the gas shows that it is colourless and has no smell. As it is heavier than air it can be poured downwards just like a liquid (Fig. 187).

Carbon dioxide is slightly soluble in water, and the solution which is thus formed turns a blue litmus paper red, just as acids do. For this reason the solution of carbon dioxide in water is often called *carbonic acid*, and the carbon dioxide itself is sometimes spoken of as *carbonic acid gas*. In naming the properties of this gas you must not forget that one which has been so frequently mentioned, namely, that it puts out the flame of a taper or match, and is consequently called a non-supporter of combustion.

Action of carbon dioxide on lime-water.—If carbon dioxide is passed from the delivery tube of an apparatus generating it into lime-water a milkiness is seen, but if the experiment is continued the milkiness by and by disappears. If the clear solution which results after the disappearance of the white powder or precipitate is boiled, the milkiness again makes its appearance. The reason of this is that the white substance of which the precipitate is formed dissolves in water which has become saturated with carbon dioxide. When the clear solution, which appears after the solution of the powder, is boiled, the carbon dioxide is driven out of it, and the liquid again becomes pure water. The precipitate reappears, because it will not dissolve in water.

The chemical change when carbon dioxide is passed into lime-water.—What are the facts taught by the experiments described? When an acid is added to the white powder formed when carbon dioxide is passed into lime-water, a brisk effervescence is noticed and the colourless, odourless gas given off is found to put out a flame. But this is just what happens when the acid is dropped on to chalk, and putting the facts together they suggest that the white powder is really chalk, so that carbon dioxide gas combines with the lime in the lime-water to form chalk. Expressing the change as an equation we can write:

CARBON DIOXIDE	unites with	LIME	to form	CHALK.

From this equation it will also be seen that chalk consists of lime and carbon dioxide. Further evidence of the truth of this will be given later.

Uses of carbon dioxide.—The fact that carbon dioxide is a non-supporter of combustion is made use of in many forms of chemical fire extinguishers, which are generally solutions which on heating evolve carbon dioxide. As burning cannot take place in this gas, the flames are therefore extinguished when the gas reaches them.

The solubility of carbon dioxide in water is increased by pressure, and the sparkling nature of the various aerated waters, like soda-water, is due to the carbon dioxide with which they have been charged at high pressures, and escapes when the pressure is reduced to that of the atmosphere by opening the

bottle. As the pressure is very great, the bottles have to be very thick.

Carbon dioxide is also produced during fermentation, the "rising" of bread being due to the escape of the gas which is generated by the fermentation of the saccharine matters formed from the starch under the influence of the yeast.

Carbon dioxide will not support life, and is sometimes used for suffocating dogs.

By cold and pressure carbon dioxide may be liquefied and also solidified, forming a soft, white substance, which when mixed with ether forms a powerful freezing mixture, the temperature sinking to about $-100°$ C.

Occurrence of carbon dioxide.—Carbon dioxide has been already stated to exist in the atmosphere, and to be produced by the oxidation of animal and vegetable tissues ; while further, under the influence of sunlight it is reconverted by the green parts of plants into its constituents, of which the carbon is used by the plant in the formation of new tissue. It is also found in many natural gaseous emanations, and is frequently present to a large extent in the gases of caves and underground passages, where, owing to its high density, it tends to accumulate if formed by fermentation or other natural processes. In expired air carbon dioxide is present to the extent of about 4·7 per cent. Although such air is not again respirable, this is partly due to the diminution of the oxygen, and it is doubtful whether carbon dioxide has any direct poisonous effect. The proportion of carbon dioxide may be increased to even 20 per cent. without immediate serious effects if only the quantity of oxygen be simultaneously increased.

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67. PRODUCTION OF CARBON DIOXIDE BY HEATING CHALK.

i. **Change produced by heating chalk.**—Place a little powdered chalk (*not* blackboard chalk) on a piece of platinum foil, and heat it strongly for some minutes in the flame of a laboratory burner. If platinum foil is not at hand, heat a lump of chalk on a piece of coarse wire gauze for some time. Or, powdered whiting may be heated on a piece of thin tinplate. The latter is, however, a long process. After heating, shake the powder on to a damp red litmus paper. Observe that the red litmus paper is in places changed to a blue colour.

ii. **Action of lime upon litmus.**—Test some wet lime with litmus paper. Observe that it changes the colour of red litmus blue.

iii. **Powder obtained by heating chalk.**—Shake up in drinking water some of the powder obtained in the Experiment 67. i. by heating chalk on platinum foil. Filter, or allow it to settle, then taste; notice the peculiar taste of lime-water.

iv. **Solution of lime in acids.**—Dissolve some lime in hydrochloric acid, and evaporate the solution to dryness. Note the formation of a white solid, which rapidly absorbs moisture from the air and liquefies. It has been previously used in experiments under the name of *calcium chloride.*

v. **Composition of chalk.**—Place a few small pieces of chalk in a test-tube. Add dilute hydrochloric acid until the effervescence, due to the production of carbon dioxide, ceases. Filter the solution remaining in the test-tube and evaporate it. Notice the substance left; it is not chalk, but calcium chloride.

vi. **Slaking of lime.**—To a lump of fresh lime add a little cold water. Observe that the mass gets very hot and swells up.

Chalk undergoes a change when heated.—It is easy to prove by putting some powdered chalk upon a piece of moist red litmus paper that this substance is unable to change the colour of the paper. If, however, some powdered chalk be strongly heated on a piece of platinum foil in a laboratory burner and then placed on a piece of moist red litmus paper, the red colour is changed to blue. The chalk undergoes some change when heated, or it would not acquire this new property. The same chemical change takes place on a very large scale in the limekiln, as occurs when a little powdered limestone, or some chalk, is heated on platinum foil. In other words, when chalk and limestone are strongly heated they are changed into quicklime. The change is brought about by driving carbon dioxide out of the limestone.

CHALK	when heated splits up into	LIME	and	CARBON DIOXIDE.

Changes produced by adding acid to chalk.—When hydrochloric acid is added to a little chalk a brisk effervescence occurs and a colourless, odourless gas which turns lime-water milky is given off.

If hydrochloric acid is poured upon a known mass of chalk, in such a way that all the gas evolved is got rid of, it is found that the proportional loss of mass of the chalk is equal to the loss of

mass on heating, thus showing that chalk contains a definite proportion of carbon dioxide gas.

If the solution remaining after the effervescence of the chalk with the acid has ceased is filtered and evaporated, a new substance known as *calcium chloride* is obtained. So that from chalk and hydrochloric acid it is possible to produce carbon dioxide, calcium chloride, and water (which is driven off by evaporation).

Substances which, like chalk, evolve carbon dioxide when acted upon by an acid are known as *carbonates*, and numerous carbonates exist, all possessing similar characteristics. Many of these on heating also give off carbon dioxide, the residue being known to be an oxide of a metal, so that they consist of carbon dioxide and a metallic oxide.

This leads to the idea that lime is also the oxide of a metal, and this view is now known to be correct, the metal being named *calcium*. Lime, therefore, is *calcium oxide* and chalk *calcium carbonate*.

Lime.—Lime produced by heating chalk or limestone—both of which are carbonates—is a white solid, which, if heated sufficiently, glows and emits a brilliant white light. It is on this account employed for the production of the limelight, where a small, hard cylinder of lime is strongly heated in an oxy-hydrogen or oxy-coal-gas flame.

When water is added to freshly-burnt lime, or *quicklime*, as it is termed, the water combines with it with the evolution of a large amount of heat, which is enough to boil the water if the quantity of lime is large. This can be seen at any time when bricklayers are preparing lime for making mortar. This addition of water to lime is called *slaking* it, and the altered lime is known as *slaked lime*. Lime dissolves to a slight extent in water, forming lime-water.

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68. COMPOUNDS OF CARBON AND HYDROGEN.

i. Preparation of marsh gas.—Heat about 10 grams of sodium acetate in an evaporating basin until it has lost its water of crystallisation (p. 234) and appears white and powdery. Mix it with the same mass of soda-lime,* and transfer the mixture to a hard glass

* Soda-lime can be obtained from a chemical apparatus dealer. It is a mixture of caustic soda and quicklime.

tube or flask, and attach an india-rubber stopper and delivery tube. Heat the tube or flask strongly. A gas is given off which can be collected over water. Collect a few jars of the gas.

ii. **Properties of marsh gas.**- (*a*) As in Experiment 60. iv., where the lightness of hydrogen is demonstrated, show that marsh gas is very light.

(*b*) Reread Experiment 60. iii., and then show that marsh gas. like hydrogen, burns, but will not support combustion.

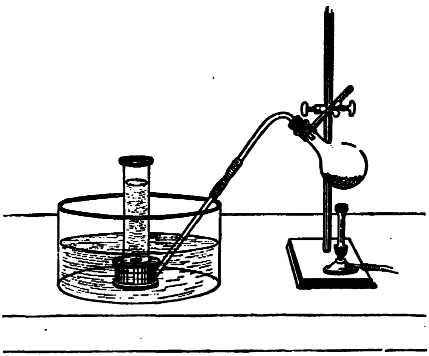

FIG. 188.—Marsh gas can be prepared by heating strongly a mixture of sodium acetate and soda-lime.

Compounds of carbon with hydrogen.—Carbon also forms compounds with hydrogen, direct union occurring when the electric arc is produced between carbon poles in an atmosphere of hydrogen. The compound resulting is known as *acetylene.* It burns with a highly luminous flame, and is present to a small extent in the products of the incomplete combustion of coal gas. It is now prepared largely by the action of water on *calcium carbide*, and its cleanliness and ease of preparation will probably lead to its wider use as an illuminant.

Ethylene, another compound of carbon and hydrogen, is a product of the destructive distillation (p. 258) of coal, wood, etc. It is hence present as a constituent of coal gas. It is readily obtained by heating a mixture of alcohol and sulphuric acid. Like acetylene, it burns with a bright, but less luminous flame. At low temperatures it may be liquefied, and by allowing the liquid ethylene to rapidly evaporate, the temperature is so greatly reduced that air may be liquefied.

Marsh gas.—Marsh gas, or methane, occurs naturally, being a product of the decomposition of vegetable matter. It is often found rising to the surface of swamps, and thus obtains the name marsh gas. It is also frequently met with in coal mines, when it is known as *fire damp.*

Being an inflammable gas, its presence in collieries is a source

of great danger, and many disastrous explosions have been caused by its ignition. It must be pointed out, however, that finely divided coal dust has also been shown to be capable of causing explosions, and it is possible that many accidents regarded as being due to the presence of marsh gas were in reality caused by coal dust. Indeed, coal dust appears to produce more violent explosions even than marsh gas.

When marsh gas burns in air or oxygen it gives rise to the formation of water and carbon dioxide.

The effects of the products of combustion of marsh gas in a coal mine are often more fatal than those of the explosion itself. The carbon dioxide constitutes the much dreaded *after damp*, and, as has been already learnt, this gas causes suffocation.

In the laboratory, methane is usually prepared by heating a mixture of sodium acetate and soda lime (Fig. 188). When pure the gas is colourless, odourless, insoluble in water, and burns with a feebly luminous flame.

69. COAL GAS.

i. **Distillation of coal.**—(*a*) Heat some coal dust in a hard glass tube to which an india-rubber stopper and delivery tube are attached. After a time apply a lighted taper to the end of the delivery tube, and satisfy yourself that an inflammable gas is given off.

(*b*) Pass the gaseous products into a little water. After a time test the water with a red litmus paper. Notice it is turned blue (p. 300).

ii. **Some properties of coal gas.**—(*a*) Fill a small toy balloon with coal gas, and demonstrate that the gas is lighter than air.

(*b*) Fill a cylinder with coal gas, as shown in Fig. 1, and observe the colour and smell of the gas. That it can be collected over water in this way shows it is insoluble in water.

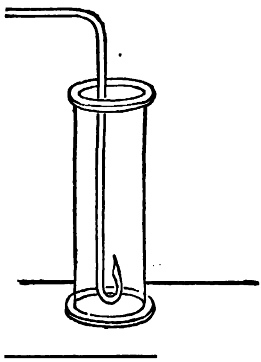

FIG. 189.—How to burn gas in a jar.

iii. **Products of the combustion of coal gas.**—By means of a bent glass tube and a piece of india-rubber tubing attached to the gas supply, as shown in Fig. 189, allow a small jet to burn in a cylinder. Notice the formation of drops of water on the sides of the cylinder.

Remove the gas jet. Add a little clear lime-water, and shake it up and down the cylinder. The lime-water is turned milky, showing the presence of carbon dioxide.

Manufacture of coal gas.—Coal gas is prepared by what is called the *destructive distillation* of coal. This process consists in heating the coal in closed retorts out of contact with the air, and collecting the products which distil over. The retorts are made of fire-clay, which are kept for about four hours at a red heat. At the end of this time all the volatile products have been driven off and practically pure *coke* is left behind.

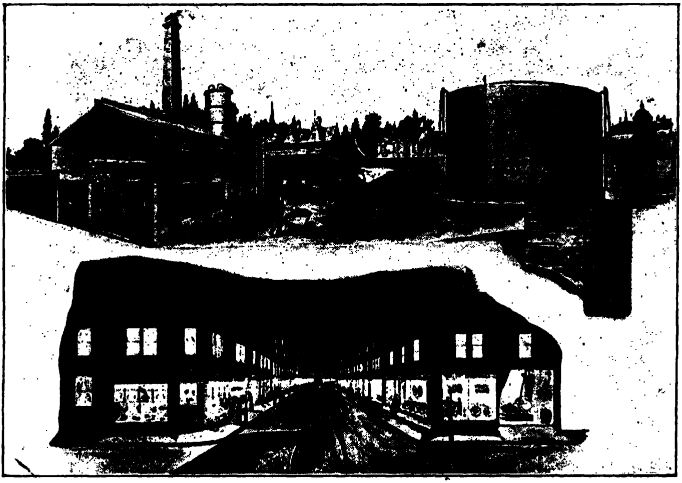

FIG. 190.—Manufacture and uses of coal gas. Reduced, by permission, from a diagram in Messrs. G. Philip and Sons' "Typical Object Lesson Pictures."

The gaseous products thus driven out of the coal leave the retorts by means of vertical pipes, and pass into a horizontal half-round pipe of considerable size called the *hydraulic main*, where coal tar and an impure solution of ammonia gas in water, called ammoniacal liquid, are condensed. The vertical pipes terminate in what are known as dip pipes, which descend a few inches below the surface of the collection of tar and ammoniacal liquor that fills the half-round bottom of the hydraulic main.

The gas enters this main through the dip pipe, bubbles through the liquid, and escapes from the main by means of a large pipe which conveys it to the condensers. The object of the dip pipe is to provide a seal which will prevent the return of any gas to the retorts. The tar and ammoniacal liquor, as they accumulate in the hydraulic main, are conducted through a trap to what is known as the *tar and ammoniacal liquor well.*

The *condensers* are two in number, each consisting of a huge cast-iron box filled with a mass of vertical tubes extending between two sheets of tubes arranged a few feet from the bottom and from the top of the condensers. Circulating water is kept continually flowing around the tubes, while the gases from the retorts are made to travel alternately up and down through the tubes until they have traversed the whole length of the condensers.

At the opposite end from which it entered, the gas is led from the condensers by a large main and passes through what is known as the *exhausters*, which serve to draw the gas through the condensers from the retorts and force it through the *scrubbers* and *purifiers* on its way to the holders.

From the exhausters the gas is forced through a large valve into the bottom of two huge circular towers technically known as "scrubbers," which are of two kinds; they are either towers filled with coke over which water slowly trickles, or they are closed compartments provided with a revolving shaft bearing horizontal circular plates, which, being wet, expose the gas to a large surface of water, and thus the last traces of ammonia are removed. The tower, which is built of sheet iron, consists of an inner and an outer shell, this construction being adopted to guard against freezing in severe winter weather.

After leaving the scrubbers the gas is conducted through a large valve to a series of purifiers, where whatever carbon dioxide and sulphuretted hydrogen remain are abstracted, together with some of the other sulphur compounds. The carbon dioxide must be removed, because it would lessen the illuminating strength of the gas, while the sulphuretted hydrogen must be completely taken out on account of its obnoxious smell and poisonous character.

Formerly the scrubbers only contained freshly slaked lime which combined with the impurities under consideration; it is now more common, however, to use a compound of iron with

hydrogen and oxygen, known as hydrated oxide of iron, to absorb the sulphuretted hydrogen in all the scrubbers except the last, which still contains freshly slaked quicklime to remove the last traces of carbon dioxide. After having been measured in a suitable meter, the gas is passed into large holders called *gasometers*, from which it passes into the supply *mains*.

Composition of coal gas.—Coal gas is a mixture of gases which may be present in different proportions. By far the most abundant constituents are hydrogen and marsh gas. These, with a compound of carbon and oxygen, called carbon monoxide, which is present to the extent of about 5 per cent., are all of them combustible gases, but they none of them burn with bright flames. These three gases may be called the *combustible non-illuminating* constituents. The illuminating power of coal gas is due to the presence in it of acetylene, ethylene, and benzene, which altogether are present only to the extent of about 5 per cent. The last three mentioned compounds of carbon and hydrogen are, therefore, the *combustible illuminating constitutents.* We may consequently write:

Coal gas contains	Combustible non-illuminating constituents.	Hydrogen. Marsh gas. Carbon monoxide.
	Combustible illuminating constituents.	Acetylene. Ethylene. Benzene.

In addition to these substances there are usually several impurities present in coal gas, among which nitrogen is the chief. Oxygen, carbon dioxide, and carbon bisulphide occur, but only in very minute amounts.

CHIEF POINTS OF CHAPTER XVIII.

Carbon is present in all living matter. When organic substances are moderately heated, a black residue largely composed of carbon is left. If the temperature is raised, the carbon burns away and an almost colourless ash is left.

Carbon exists in several **allotropic forms**. Two of these, *diamond* and *graphite*, are crystalline. Non-crystalline or *amorphous* carbon is known in varying degrees of purity as *coke*, *gas carbon*, *wood charcoal*, and *animal charcoal.*

Burning.—When candles, gas, wood, or any substance which contains carbon burns in the air or oxygen, carbon dioxide is formed. Similarly, carbon dioxide results by the combustion of any form of

carbon in air or oxygen. Carbon dioxide is also given off in the breath of animals. From these sources large quantities are continually passing into the atmosphere.

Breathing is really a kind of burning; the oxygen taken into the body by the lungs unites with the carbon in the body to form carbon dioxide, and with the hydrogen to form water; these products are expelled from the body partly in breathing.

The presence of carbon dioxide in the air may be shown by exposing lime-water in a shallow vessel. The lime-water soon becomes coated with a thin layer of chalk.

The green parts of plants have the power in bright sunlight of breaking up carbon dioxide; the carbon they keep to build up their solid parts, and oxygen is given off into the air.

Animals give off carbon dioxide (which passes into the air) and take oxygen from the air. Plants give out oxygen and take carbon dioxide from the air; in this way both are supplied from the air with the substances they need.

Preparation of carbon dioxide.—When chalk or limestone is heated it loses about 44 per cent. of its weight. This is due to the loss of carbon dioxide. The residue left behind is *lime*. The same gas is evolved when either chalk or limestone is acted upon by hydrochloric acid. By ascertaining the weight per cent. of carbon dioxide which is given off by the chalk, we can prove that chalk is really a compound of lime and carbon dioxide.

Carbon dioxide is a heavy gas which does not burn nor support combustion. It is slightly soluble in water, the solution acting as a weak acid which turns blue litmus to a port-wine colour. This solution may be regarded as *carbonic acid*. The solubility of carbon dioxide in water is increased by pressure. By cold and pressure carbon dioxide may be liquefied, and also solidified to a soft white substance which, when mixed with ether, forms a powerful freezing mixture.

Lime is a white solid which is unchanged by heating. When heated intensely it glows and emits a brilliant white light. It dissolves in hydrochloric acid to form *calcium chloride*. When wet, lime turns a red litmus paper blue. When freshly made it is called *quicklime*. Quicklime combines with water, being changed into *slaked lime*.

Compounds of carbon with hydrogen.—Acetylene, marsh gas, and ethylene are all compounds containing only hydrogen and carbon. They are all combustible gases.

Marsh gas is also known as *methane*. Besides occurring over marshes it is often found in coal mines, when it is known as *fire damp*.

Coal gas consists of a mixture of hydrogen, carbon monoxide, marsh gas, and other hydrocarbons. It is obtained from the destructive distillation of coal.

EXERCISES ON CHAPTER XVIII.

1. Describe and explain the changes which take place when (*a*) limestone is burnt in a kiln; (*b*) water is added to some freshly burnt lime. (P.T., 1897.)

2. Charcoal burnt in air or oxygen in a bottle containing lime-water produces a white precipitate in the lime-water. This white precipitate, if collected and mixed with hydrochloric acid, dissolves with effervescence. What experiments would you make in order to compare the gas thus obtained with that obtainable by a similar process from the breath? (1897.)

3. Describe the apparatus you would use for the production and collection of carbon dioxide gas; name the materials required, and describe the properties of the gas. (1898.)

4. Three bottles filled with colourless gas are placed before you containing (*a*) hydrogen, (*b*) nitrogen, and (*c*) carbon dioxide. Describe experiments you would make in order to distinguish them from one another, and from other gases. (1897.)

5. How is lime distinguished from limestone as to composition and properties? (1897.)

6. What is meant by an allotropic form of an element?

Give examples of allotropic forms, stating in each case in what ways these forms differ one from the other. (1898.)

7. Describe, giving a sketch of the apparatus, how you would obtain a jar full of carbon dioxide gas.

What experiments would you make to exhibit the properties of this gas? (1899.)

8. Describe experiments to show that charcoal is porous. (1899.)

9. Four bottles are given you containing oxygen, hydrogen, nitrogen, and carbon dioxide respectively. By what experiments would you distinguish these gases from one another? (1899, Day.)

10. Describe the appearance of the three different forms of carbon.

By what experiments would you prove that they are really only different forms of the same element? (1899, Day.)

11. What is the chemical nature of the sediment formed in kettles in which hard water has been boiled, and why is it formed?

If you treat the sediment with hydrochloric acid, what reaction takes place? (1899, Day.)

12. What is (*a*) "fire damp," (*b*) "after damp"? What are the dangers due to the presence of much fire damp in mines?

13. What is marsh gas? Why is it so called? What are its properties?

14. What does coal gas consist of? What products are formed by its combustion, and how would you endeavour to experimentally prove your answer?

CHAPTER XIX.

COMMON SALT. HYDROCHLORIC ACID. CHLORINE.

70. COMMON SALT.

i. **Common salt is soluble in water.**—Shake a little common salt with water in a test-tube for some time. Allow the undissolved salt to settle, and taste a little of the clear liquid. The taste of the solution is proof enough that common salt is *soluble in water*.

ii. **Common salt crystallises in cubes.**—Evaporate some of the clear solution by gently heating it in an evaporating basin, and when the basin is dry examine the residue. Careful inspection will discover small cubes, the shape of some of which can be recognised by the unaided eye. The cubical shape of other particles can be easily made out under a magnifying glass.

iii. **The solution of salt in water is neutral.**—Test another portion of the clear solution of common salt with blue and red litmus papers in succession. The colour of neither paper is altered. Or, the solution of common salt in water is neutral.

iv. **Salt crystals contain no water.**—Heat a little *dry* salt in a test-tube. Notice the crackling and the absence of water on the side of the tube.

v. **Action of strong sulphuric acid on salt.**—Place a little dry salt in a test-tube and pour upon it some strong sulphuric acid. Gently warm the test-tube. Observe that a gas is given off, the part of which in the tube is colourless, though on coming into contact with the air at the mouth of the tube it fumes strongly. Plunge a lighted match into the tube, and notice that the flame is extinguished. Place a piece of moist blue litmus paper at the mouth of the tube, and observe that it is turned red, but the paper is not bleached.

Properties of common salt.—Common salt crystallises in six-sided solids, or cubes (Fig. 191). When the crystallisation is brought about by evaporating a solution of salt, the crystals are very small. Some natural crystals, known as *rock salt*, are, however, of a considerable size. There is no water of crystal-

lisation in the crystals, and consequently when they are heated no steam is given off. The crackling noticed when salt crystals are heated in a tube is spoken of as *decrepitation*, and is due to the breaking up of the crystals into smaller pieces.

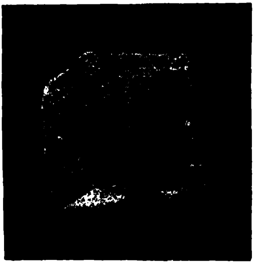

FIG. 191.—A cube of rock salt. (From a photograph by Mr. H. E. Hadley.)

Common salt dissolves in water, and the amount dissolved by cold water is almost as great as by warm water. The solution has no action on litmus papers, and is said to be *neutral*.

Rock salt is found in the earth in some countries as layers of varying thickness. The largest amount is found in the salt mines of Austria, but considerable quantities are found in this country, in Cheshire. Common salt is also present in large quantities in sea water, but is mixed with other substances.

It is used largely to prevent the decomposition of meat, and enormous quantities are employed in the manufacture of sodium carbonate.

71. HYDROCHLORIC ACID.

i. **Preparation of hydrochloric acid gas.**—Fit up the apparatus shown in Fig. 192. Remove the india-rubber stopper of the flask and place in it a small quantity of rock salt in small pieces, or some thoroughly dried common salt. Pour some strong sulphuric acid into the wash-bottle shown in the middle of the illustration. Re-insert the india-rubber stopper into the flask and pour down the acid funnel enough of a mixture* of strong sulphuric acid and water to cover the salt in the flask. Gently warm the flask. Collect jars of the gas which is evolved (after it has bubbled through the strong sulphuric acid in the wash-bottle and so become freed from water vapour) in gas jars by downward displacement in the way the illustration makes clear. When each gas cylinder is full, which you can tell by holding a blue litmus paper just below the top of the outside of the cylinder until it is turned red, cover it with a ground glass plate, with the ground side underneath. As the cylinders are

* One part of acid and one of water are convenient proportions. Be careful to gradually pour the acid into the water and not the water into the acid when mixing them, keeping the mixture well stirred throughout the process.

filled set them on one side for examination as presently described. Collect four jars of gas in this way.

ii. **Properties of hydrochloric acid gas.**—(*a*) Raise the glass plate from the first jar and plunge a lighted taper into the gas. The flame is extinguished and the gas does not burn. Quickly replace the glass plate.

(*b*) Into the same jar drop a piece of moistened blue litmus paper and replace the glass plate. The paper is turned red, showing the gas has acid properties. Notice carefully that the paper is not bleached.

(*c*) Observe the fumes which the gas forms with the air when the glass plate is removed from a cylinder full of the gas. This is due to the very strong power of absorbing moisture possessed by hydrochloric acid gas.

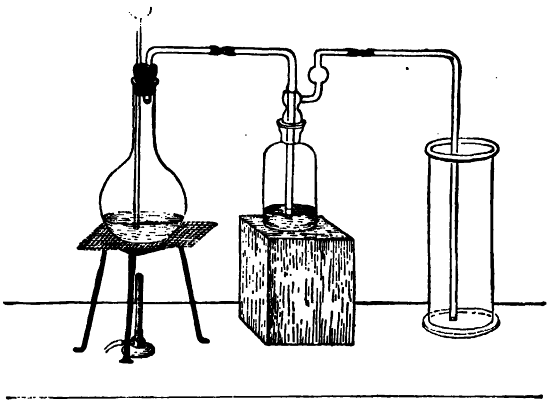

FIG. 192.—Preparation and collection of hydrochloric acid gas.

(*d*) Firmly pressing the glass plate, invert a cylinder full of the gas and place it upside down in a basin of water. Remove the plate when it is under water, and notice that water rushes up and completely fills the jar. If it does not completely fill the jar, it shows that the air in the jar was not altogether displaced by the gas when you should have filled it.

iii. **Solution of hydrochloric acid gas in water.**—Modify the apparatus shown in Fig. 192. Remove the gas cylinder and the delivery tube which dips into it: Pour out the sulphuric acid from the wash-bottle, which thoroughly wash and half fill with water. If there is still enough salt and sulphuric acid in the flask, again warm it gently and allow the evolved gas to bubble into the water. Notice that it is completely dissolved. The solution of hydrochloric acid gas formed in this way is the "hydrochloric acid" of commerce.

iv. **Some metals turn hydrogen out of hydrochloric acid.**—Pour some of the solution prepared in the last experiment upon a few

pieces of zinc, or iron, in a test-tube. Place your thumb over the end of the tube, and after a minute or two remove your thumb and apply a lighted taper to the open end of the test-tube. Notice the slight explosion and the flame of burning hydrogen.

v. **Other proofs that hydrochloric acid contains hydrogen.**—(*a*) Prepare hydrochloric acid gas in the manner described in Experiment 71. i. in the flask *A* (Fig. 193). Pass the gas so obtained over heated copper oxide in the hard glass tube *BC*. Observe that water collects in the test-tube *D*, and that the copper oxide is converted into a green substance. As water is formed the hydrochloric acid must evidently contain hydrogen.

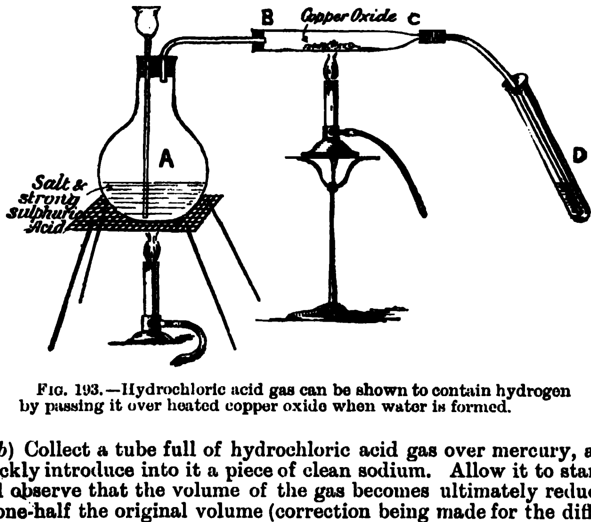

Fig. 193.—Hydrochloric acid gas can be shown to contain hydrogen by passing it over heated copper oxide when water is formed.

(*b*) Collect a tube full of hydrochloric acid gas over mercury, and quickly introduce into it a piece of clean sodium. Allow it to stand, and observe that the volume of the gas becomes ultimately reduced to one-half the original volume (correction being made for the difference in pressure), while, further, the sodium gets covered with a white powder which you may satisfy yourself is salt. Test the gas left with a lighted taper and see that it has the properties of hydrogen.

vi. **Composition of common salt.**—Pass hydrochloric acid gas into a solution of caustic soda (known to chemists as sodium hydrate) until the solution has no effect either on a blue or red litmus paper. Distil the resulting solution and examine both the liquid which distils over and the residue left in the retort. Observe that the liquid is ordinary water and the residue common salt, which you can prove by tasting it.

Hydrochloric acid.—When common salt is heated with strong sulphuric acid a gas is given off which forms steamy fumes in

the air. The gas readily dissolves in water, and the solution constitutes the hydrochloric acid of commerce. The solution was, because of its preparation from salt, originally known as "Spirits of Salt." Another common name given to it is Muriatic Acid. The "salt gas" itself is called hydrochloric acid gas. It is colourless, will not allow things to burn in it, nor will it burn itself. As is seen by its action on blue litmus paper, it is strongly acid. It is heavier than air, and can consequently be collected by downward displacement.

Composition of hydrochloric acid.—You have already learnt that when the element copper is heated strongly in air it combines with the oxygen of the air to form a black compound called copper oxide, which compound is evidently entirely composed of copper and oxygen.

Now, if hydrochloric acid gas is passed over heated copper oxide, which can be conveniently arranged in a tube, the black oxide is changed into a green substance, and water is formed at the same time. Moreover, if the green substance be acted upon with strong sulphuric acid, hydrochloric acid gas is again formed, just as when salt is similarly treated.

As water is formed, the hydrochloric acid gas passed over the heated copper oxide must evidently contain the hydrogen which is necessary for the formation of the water, for you know (p. 214) the copper oxide contains none. In fact, the simplest explanation of the experiment is that the hydrogen of the hydrochloric acid gas combines with the oxygen of the copper oxide to form water, while the copper combines with the other constituent of the hydrochloric acid (which you will presently learn to call *chlorine*) to form a green substance known as chloride of copper.

When metallic sodium acts upon hydrochloric acid gas contained in a tube over mercury, it is found after a short time that the volume of the gas is reduced to one-half and that the gas left in the tube is pure hydrogen. At the same time the sodium combines with the other constituent of the hydrochloric acid gas to form a white solid, which proves on examination to be common salt. These important experiments teach two facts:

1. That hydrochloric acid is composed of two constituents, hydrogen and another element, which will immediately be proved to be chlorine, combined together in equal proportions by volume.

2. Common salt is a compound of the metal sodium and the second constituent of hydrochloric acid, chlorine.

Chemical behaviour of hydrochloric acid.—Many metals, such as zinc and iron, when dropped into a solution of hydrochloric acid gas in water (which will in future be spoken of as hydrochloric acid) break up the acid, evolving hydrogen gas and combining with its chlorine to form a chloride, or,

ZINC	in action with	HYDROCHLORIC ACID	forms	ZINC CHLORIDE	and gives off	HYDROGEN.
IRON	in action with	HYDROCHLORIC ACID	forms	IRON CHLORIDE	and gives off	HYDROGEN.

When hydrochloric acid is brought into contact with sodium hydrate, also called caustic soda, a double chemical change, or *double decomposition*, takes place, common salt or sodium chloride and water being formed (Expt. 71. vi.).

HYDROCHLORIC ACID	in action with	SODIUM HYDRATE	forms	SODIUM CHLORIDE	and	WATER.

72. CHLORINE.

i. Preparation of Chlorine.—(*a*) Pour a little strong sulphuric acid upon some black oxide of manganese contained in a test-tube. Shake the tube until a paste is formed. Gently warm the tube, and after a minute or two examine the gas which fills it. It has no colour. Place a moistened blue litmus paper in the gas, and notice that, though the acid fumes redden the paper, it is not bleached.

(*b*) Repeat the experiment, but first mix the black oxide of manganese with an equal quantity of dry table salt. Again examine the gas evolved after heating the tube. It has a greenish-yellow colour. A moistened litmus paper has its colour completely removed, or it is bleached. The greenish-yellow gas is *chlorine.*

ii. Preparation of larger quantities of chlorine.—Fit up the apparatus shown in Fig. 192, and used in Expt. 71. i., for the preparation of hydrochloric acid gas. Remove the india-rubber stopper from the flask, put in some black oxide of manganese, and then enough strong hydrochloric acid to cover it. Shake the powder and acid together until no dry patches can be seen on looking through the bottom of the flask. Replace the india-rubber stopper, and be sure that the acid funnel dips beneath the surface of the liquid. Place in the wash-bottle an amount of *water* (not sulphuric acid as in preparing hydrochloric acid gas) like that shown in the figure. Gently warm the flask. Chlorine is at once given off. Collect several jars by downward displacement. You can easily

see when the jars are full as the gas is coloured. Cover the jars with dry ground glass plates. **Caution.**—*It is very distressing to breathe chlorine; this experiment should therefore be done either in the open air or in a fume-cupboard with a good draught.*

iii. **Bleaching power of chlorine.**—In the first jar place a piece of damp Turkey-red cloth, a moist litmus paper, some coloured flowers, some writing done in ordinary ink, and a moist piece of newspaper. All the articles except the piece of newspaper are bleached. Chlorine bleaches vegetable colours. Printers' ink is not a vegetable colour.

iv. **Chlorine combines spontaneously with some metals.**—Powder a small piece of antimony and gently warm the powder, on a piece of notepaper, over the flame of a laboratory burner. Lift the glass plate off a second jar of chlorine and sprinkle the warm antimony powder into the chlorine. The metal inflames on coming into contact with the gas, forming a chloride of antimony.

Or, drop a sheet of Dutch metal into a jar of chlorine. It will immediately combine with the gas with the accompaniment of flame.

v. **Chlorine has a great affinity for hydrogen.**—(*a*) Attach a wire to a candle as shown in Fig. 159. Light the candle and lower it into a jar of chlorine. Notice the candle continues to burn, but with a very smoky flame, depositing soot on the sides of the jar. The candle is composed of carbon and hydrogen. The chlorine combines with the hydrogen and leaves the carbon. Test the fumes left in the jar with a blue litmus paper and convince yourself they are acid.

(*b*) Boil a little turpentine in a test-tube and pour a drop or two of the hot liquid upon a piece of dry filter paper. When the turpentine has spread over the paper, fold it in a convenient manner, and drop it into a jar of chlorine. The turpentine at once inflames. A large quantity of carbon is thrown down, and a great deal of the steamy fumes of hydrochloric acid gas is formed. Turpentine, like a candle, is made of carbon and hydrogen.

vi. **Chlorine is soluble in water.**—(*a*) Invert a jar of chlorine in a basin of water, and notice that the water slowly dissolves the gas. The water rises up the jar, but not nearly so quickly as in the case of hydrochloric acid gas.

(*b*) Pass chlorine gas from the apparatus used in Expt. 72. ii. into a glass of water. Notice that the gas dissolves, the water eventually having the colour, smell, and bleaching power of chlorine gas. A solution of chlorine in water is called *chlorine water*.

(*c*) Leave some chlorine water for a day or two in bright sunshine. At the end of that time the chlorine water has lost its colour, smell, and bleaching power. The chlorine has combined with hydrogen to form hydrochloric acid, and oxygen has been given off. Test the liquid with a blue litmus paper, and see that it is acid.

Preparation of chlorine.—You have already learnt that hydrochloric acid is a compound of hydrogen and a second substance; and that common salt, or sodium chloride, is a compound of the metal sodium with the same second substance.

This second constituent, which is called chlorine, can be obtained separately either from common salt or from hydrochloric acid. It is more usual to prepare it from hydrochloric acid, and the plan adopted is to gently heat the solution of hydrochloric acid gas in water with black oxide of manganese, when chlorine is given off in large quantities in the form of a greenish-yellow gas.

The method used to get chlorine from common salt is to first mix it with black oxide of manganese and then to heat the mixture with strong sulphuric acid, when chlorine is evolved as in the previous case. This process is really the same as the previous one, except that instead of first preparing hydrochloric acid from common salt and strong sulphuric acid (Expt. 71. i.) and then acting upon it with black oxide of manganese (Expt. 72. ii.), the two experiments are combined. The three materials are heated together, and the hydrochloric acid as it is formed is decomposed by the manganese dioxide which is present.

Chlorine is heavier than the air and is usually collected by downward displacement, though it is sometimes collected over a strong solution of salt or over warm water.

Properties of chlorine.—Chlorine is a gas with a greenish-yellow colour, from which fact* it gets its name. It has a disagreeable smell, and the gas, if breathed, causes distressing symptoms, which have been described as like those of an exaggerated cold in the head. The gas is soluble in water and being heavier than air is usually collected by downward displacement. Its chief characteristic is its power of bleaching moist vegetable colours. Strictly speaking chlorine does not bleach. What happens is that the chlorine combines with the hydrogen of the moisture (which must be present for successful bleaching) to form hydrochloric acid and liberates the oxygen. This oxygen unites with the colouring matter to form a new chemical compound *which has no colour*, or, as chemists say, the oxygen oxidises the colouring matter. It is because of this power of liberating oxygen from water that chlorine is so useful as a disinfectant. The liberated oxygen combines with the noxious material, and, by oxidising it, renders it harmless.

The ease with which chlorine combines with hydrogen is seen not only by its action upon moisture, but in other ways. A lighted candle will continue to burn when plunged into

* χλωρὸς, greenish-yellow.

chlorine, though with a very smoky flame. A candle is composed of hydrogen and carbon, and the flame continues, though with diminished brightness, because of the heat generated by the combination of the chlorine gas with the hydrogen of the candle to form hydrochloric acid gas. The carbon set free in the process is deposited as soot. The same explanation holds true for the spontaneous combustion of warm turpentine in chlorine gas.

Chlorine readily combines with metals to form chlorides. If finely divided iron, copper, antimony, and other metals be sprinkled into dry chlorine gas they at once combine with it, the heat of combination being sufficient to cause them to inflame. This happens more readily if the metals are first warmed.

Synthesis of hydrochloric acid.—When equal volumes of hydrogen and chlorine are mixed and exposed to sunlight, or the electric light, they combine together, with great violence, to form two volumes of hydrochloric acid gas. There is, therefore, no diminution in volume. The case is simpler than that of the combination of hydrogen and oxygen to form steam. You will remember that two volumes of hydrogen combine with one volume of oxygen to form two volumes of steam, or the three volumes of the mixed gases are reduced to two after the combination has taken place. While

HYDROGEN 1 vol.	combines with	CHLORINE 1 vol.	to form	HYDROCHLORIC ACID GAS 2 vols.
HYDROGEN 2 vols.	combine with	OXYGEN 1 vol.	to form	STEAM 2 vols.

CHIEF POINTS OF CHAPTER XIX.

Common salt occurs in nature as the mineral *rock salt*. It is soluble in water, the solution formed being neutral. Its crystals contain no water of crystallisation. The crystals decrepitate when heated. When treated with warm strong sulphuric acid a gas known as hydrochloric acid gas is evolved.

Hydrochloric acid, originally known as "spirits of salt" and muriatic acid, is prepared by the action of strong sulphuric acid on common salt—the gas evolved is dissolved in water to form the hydrochloric acid of commerce.

Hydrochloric acid gas is composed of equal volumes of hydrogen and chlorine. The hydrogen can be turned out of a solution of

hydrochloric acid by the action of metals like zinc and iron. Hydrochloric acid is neutralised by sodium hydrate to form common salt.

Chlorine is easily prepared by the action of strong sulphuric acid upon a mixture of common salt and manganese dioxide. Owing to the distress caused by breathing chlorine, its preparation should be done in the open air or in a draught cupboard.

Chlorine is a greenish-yellow gas, heavier than air, and soluble in water. It is much used as a bleaching agent. It has a very great affinity for hydrogen, and easily combines with most metals to form chlorides.

EXERCISES ON CHAPTER XIX.

1. How is hydrochloric acid obtained? Give a short account of its chief properties.

2. What are chlorides? How may they be obtained? Give examples.

3. Briefly indicate the reasoning which leads to the supposition that hydrochloric acid gas contains hydrogen united with another gas, and state how this second gas may be obtained from the acid.

4. How may it be proved that hydrochloric acid gas consists of one half its volume each of (*a*) hydrogen and (*b*) chlorine?

5. Describe the properties of chlorine, and state how you would obtain the gas from salt and then reconvert it into salt.

6. Under what conditions does chlorine unite with (*a*) hydrogen, (*b*) phosphorus, (*c*) sodium?

7. A lighted taper is placed in a jar of chlorine, what happens, and why?

8. How may chlorine be (*a*) obtained from, (*b*) converted into hydrochloric acid?

9. What is the action of sulphuric acid upon salt? What are the properties of both products?

10. From hydrochloric acid how could you obtain (*a*) hydrogen, (*b*) common salt?

CHAPTER XX.

SULPHUR AND SULPHURIC ACID.

73. SULPHUR.

i. **Melting point of sulphur.**—Draw out, in the flame of a laboratory burner, a piece of glass tubing so as to make a small thin-walled tube, about two or three inches long and $\frac{1}{10}$-inch in diameter. Into this tube place some finely powdered sulphur. Tie the filled tube on to a thermometer near its bulb with a piece of fine platinum wire, and put the thermometer into a beaker of sulphuric acid which has been placed over a burner. (Be very careful not to upset the acid.) Gradually heat the acid and keep it at a uniform temperature by moving the curved stirring rod (shown in Fig. 194) up and down. Notice when the sulphur melts, and at that instant read the thermometer. This reading will be the melting point of the sulphur.

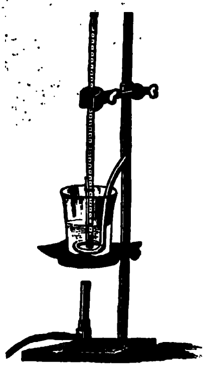

FIG. 194.—Determination of the melting point of sulphur.

ii. **Effects of heat upon sulphur.**—(*a*) Put some finely powdered sulphur into a large test-tube, using sufficient to fill the tube to a height of about 1½ inches, and heat carefully with a small laboratory burner flame. Occasionally take the tube out of the flame and shake it. When the sulphur has all melted notice that an amber coloured liquid has been formed. Pour a little of the liquid into a beaker of water. Observe that a lump of yellow sulphur is again formed, which when broken reveals a crystalline structure.

(*b*) Continue to heat the remainder of the liquid sulphur obtained in (*a*) until the liquid boils. Carefully observe the changes in colour of the liquid. Pour a little of the boiling liquid into cold water. Examine the cooled sulphur, it is *plastic* and not unlike india-rubber.

(*c*) Notice that a yellow deposit has been formed on the cold, upper part of the test-tube in which the sulphur was heated. This is the result of the condensation of sulphur vapour. The deposit is known as *flowers of sulphur*.

iii. **Plastic variety of sulphur.**—After examining the plastic solid which results from suddenly cooling boiling sulphur, weigh a lump of it and place it on one side for a few days. After this interval examine it again and weigh it. There is no alteration in mass, but the lump has changed again to ordinary sulphur.

iv. **Crystalline varieties of sulphur.**—(*a*) Dissolve some powdered roll sulphur in carbon bisulphide. The solution must be made entirely by shaking, for *the carbon bisulphide must on no account be heated.* When the sulphur has all dissolved, pour the solution into an evaporating basin, and put it into a place free from dust to slowly evaporate. Examine the basin after an hour or so. Observe the crystals which have formed. Take the largest and most perfect and sketch its form. This kind of crystalline sulphur is known as the *octahedral variety.*

(*b*) Place some powdered roll sulphur in a clean, dry, evaporating basin and heat gently on a piece of iron wire gauze. When it has all melted, remove the flame and allow it to cool. As soon as a solid film has formed on the top of the liquid, pierce two holes in it and quickly pour out the remaining liquid sulphur through one of the holes. Remove the film of solid sulphur and examine the yellow, needle-shaped crystals on the sides of the basin. This kind of crystalline sulphur is known as the *prismatic variety.*

Examine the crystals after a few days. Observe they are now opaque. The prismatic sulphur has changed back again to ordinary sulphur.

v. **Sulphur can be obtained from some minerals.**—Procure a little of the brass-like mineral called *iron pyrites.* Heat a fragment or two in a hard glass tube. Notice that melted sulphur gradually collects on the cold part of the inside of the tube.

How sulphur is found in nature.—The non-metallic element, sulphur, is found naturally both alone, that is in an uncombined condition, and also united with other elements in the form of chemical compounds. The uncombined or *native sulphur* is rarely pure. It is found most abundantly in the neighbourhood of volcanoes, as, for example, in Sicily, from which island a large part of the *brimstone,* as sulphur is commonly called, of commerce is obtained. Before being placed on the market the sulphur is purified, or separated from the earthy impurities by distillation in suitable retorts connected with large cool chambers in which the sulphur vapour, driven off by heating, is condensed. In the first stages of the process the sulphur condenses as "flowers of sulphur," but later, when the condensing chambers have become heated, as a liquid on the floor. This liquid is cast into the familiar "roll-sulphur" or brimstone which is well known to most people.

Sulphur occurs naturally combined with other elements in

the form of *sulphides* and *sulphates.* The sulphides are compounds of sulphur with metals, among the most common being :

Galena,	containing	lead and sulphur.
Blende,	"	zinc and sulphur.
Iron pyrites,	"	iron and sulphur.
Copper pyrites,	"	copper, iron, and sulphur.

The naturally occurring sulphates are compounds of sulphur with metals and oxygen. Their constitution will be better understood after sulphuric acid has been studied. The most common mineral sulphates found in the earth are gypsum or calcium sulphate containing calcium, sulphur, and oxygen ; and heavy-spar or barium sulphate, containing barium, sulphur, and oxygen.

Sulphur is also present in some of the compounds contained in animal and vegetable tissues.

Varieties of sulphur.—Sulphur is one of a few elements which exists in several forms. When an element has more than one modification, all of them with the same chemical composition but possessed of different physical properties, such as density, colour, crystalline form, and so on, it constitutes an instance of what is called *allotropy*, and the different varieties of the element are called *allotropic* forms. Sulphur, oxygen, carbon, and phosphorus, are elements with allotropic forms. Sulphur has four allotropic forms, though it is only necessary here to mention three of them. These are *octahedral*, *prismatic*, and *plastic* sulphur. It must be carefully borne in mind that though the properties of these varieties of sulphur are so different, yet all the varieties are composed entirely of sulphur.

Octahedral sulphur.—Ordinary roll-sulphur, or brimstone, is composed of tiny crystals of this variety of sulphur compactly welded together. This can be seen by breaking a roll of sulphur in two and examining the broken ends, when crystals will be distinctly visible in the centre of the roll. But much larger crystals are obtained by dissolving powdered roll sulphur in carbon bisulphide and allowing the solution to slowly evaporate into the air, when fairly large, perfectly formed octahedra of sulphur will be obtained. This kind of sulphur is the most *stable* form, the other varieties gradually change into octahedral sulphur if left to themselves exposed to the air.

Prismatic sulphur. — The second crystalline variety of

sulphur is called *prismatic* sulphur. It is obtained in the form of clear, needle-shaped crystals by carefully melting powdered roll-sulphur in an evaporating basin and allowing the liquid obtained to cool slowly. As soon as a film of solid sulphur has formed on the liquid sulphur, two holes are pierced, and the remaining liquid rapidly poured through one of them. If the film be removed and the inside of the basin examined, a number of clear, needle-shaped crystals of prismatic sulphur are seen. But when the basin is examined again after an interval of a few days the crystals are no longer clear, they have become opaque owing to the transformation of each needle into a number of minute crystals of octahedral sulphur, which, as has been remarked, is the stable form of sulphur.

Plastic sulphur.—If some boiling sulphur, which may be obtained by melting powdered roll-sulphur in a large test-tube, is suddenly cooled by pouring it into cold water, it undergoes a remarkable change. If a piece of the sulphur, solidified in this manner, is taken out of the water and examined, it is found to be like caoutchouc; it can be pulled about like chewing gum, and it is quite as elastic. This springy material is plastic sulphur. But if plastic sulphur be left to itself for a day or two it gradually changes back into octahedral sulphur, another reason for regarding the octahedral as the *stable* form of the element. In this process of reconversion there is no change of mass.

Effects of heat upon sulphur.—Sulphur undergoes a series of changes as it is heated. To follow the changes satisfactorily the heating must be very gradual. When powdered roll-sulphur is heated in a large test-tube it first melts, at about 114° C., into an amber-coloured liquid, which when poured into cold water solidifies into ordinary yellow sulphur. On continuing to heat the melted sulphur above 114° C., however, it gradually gets darker and darker in colour, becoming thicker and thicker in consistency, until at about 250° C. it is so viscid (p. 2) that the tube containing it can be inverted and the liquid will not flow. But if the temperature be still further raised the thick liquid becomes mobile again, and by and by, at 440° C., it boils, changing into a dark orange-red vapour. The vapour, by sudden cooling, can be changed into a yellow solid, known as "flowers of sulphur." If the boiling sulphur be poured into cold water it is converted into plastic sulphur.

74. OXIDES OF SULPHUR.

i. **Burning of sulphur in air.**—Place some sulphur in a deflagrating spoon (Fig. 198) and hold the spoon in the flame of a laboratory burner. Notice that the sulphur burns with a feeble, pale blue flame. Notice the suffocating fumes of "burning sulphur," which you have learnt (p. 224) to call sulphur dioxide.

ii. **Burning of sulphur in oxygen.**—Refer to Expt. 58. v., and bear in mind sulphur dioxide is also formed in this case, and that the experiment shows the gas is soluble in water and that the solution has an acid reaction.

iii. **Bleaching power of sulphur dioxide.**—Remove the stopper from a bell-jar, and replace it by a tightly fitting cork through which a wire with a hook on the lower end is passed. Suspend a few brightly coloured flowers by a thread from the hook. In a small basin place some fragments of brimstone, and with the aid of the flame of a laboratory burner set the sulphur alight. Place the bell-jar with the flowers in it over the burning sulphur. Notice that after a time the flowers are bleached.

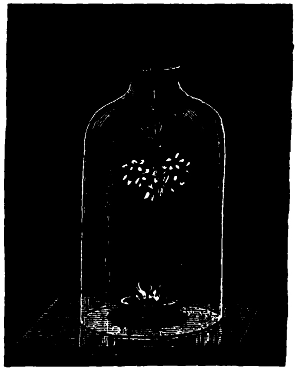

FIG. 195.—The fumes formed when sulphur burns in air will bleach flowers.

iv. **Sulphur dioxide can be obtained from sulphuric acid.**—(*a*) Into a little moderately strong sulphuric acid contained in a large test-tube drop a few copper turnings and allow the metal and acid to remain in contact for some minutes. No action ensues. Copper has no effect on *cold* strong sulphuric acid.

(*b*) Carefully warm the test-tube, holding it by means of a holder away from your face. As soon as the acid gets *hot*, large quantities of sulphur dioxide are given off. Continue the heating for some time in a good draught cupboard or in the open air.

Now put a little water into a beaker and pour the contents of the test-tube into it. Shake the liquids together in the beaker and filter the mixture. The liquid which filters through is blue. Evaporate some of the blue solution in a basin nearly to dryness and leave the remaining liquid for some time. Observe the clear blue crystals which are formed. These crystals are blue vitriol or copper sulphate.

Oxides of sulphur.—Sulphur forms two different compounds with oxygen, one called *sulphur dioxide*, the other *sulphur trioxide*. The latter compound contains half as much oxygen again as the former.

Sulphur dioxide.—The simpler oxide of sulphur is formed when sulphur burns in air or oxygen. The only difference in the two cases of burning is that when the sulphur combines with the oxygen of the air the combustion is feebler, and the sulphur dioxide formed is mixed with the nitrogen of the air; when the burning takes place in pure oxygen it is much more brilliant, and the sulphur dioxide formed is pure.

Sulphur dioxide is most commonly obtained in the laboratory in larger quantities by acting upon hot, strong sulphuric acid by means of copper or mercury. It can easily be shown, by heating copper in strong sulphuric acid, that

COPPER in action with SULPHURIC ACID forms COPPER SULPHATE and SULPHUR DIOXIDE.

In preparing the gas, the apparatus shown in Fig. 192 is employed, without the wash-bottle, and, as in the case of chlorine and hydrochloric acid gas, sulphur dioxide is collected by *downward* displacement. This is because the gas is heavier than air and soluble in water.

Bringing together the properties of sulphur dioxide, which different experiments already described have demonstrated, it may be said to be a colourless gas, with a suffocating odour, heavier than air, soluble in water forming an acid solution, and possessed of strong bleaching powers. Its bleaching powers are made use of commercially in the preparation of straws and silks. It will not burn nor support combustion.

Sulphur trioxide.—Sulphur dioxide can be made to combine

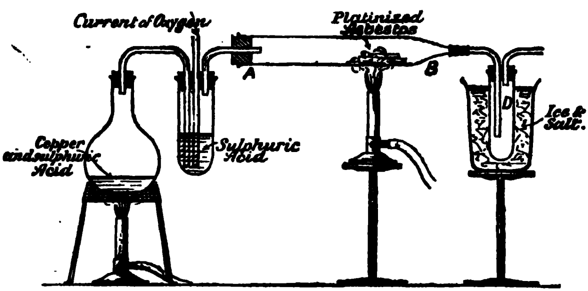

FIG. 196.—Apparatus for preparation of sulphur trioxide.

with a further quantity of oxygen. The process is not so straightforward as most of those already described, but it is

not difficult to understand. A mixture of sulphur dioxide and oxygen is passed over heated platinised asbestos. [Platinised asbestos is prepared by dipping asbestos fibres into (1) platinic chloride solution, (2) ammonium chloride solution, and heating strongly. By this means the asbestos becomes coated with a quantity of very finely divided platinum.] White fumes are formed in abundance, and when cooled sufficiently they change into a white powder, or crystals, known as *sulphur trioxide*. The apparatus necessary for the purpose is shown in Fig. 196.

SULPHUR DIOXIDE	combines with more	OXYGEN	to form	SULPHUR TRIOXIDE.

The crystals of sulphur trioxide obtained in the above process are very soluble in water, the solution being accompanied by a hissing noise as when the oxide of phosphorus (p. 226) dissolves in water. The solution obtained is *sulphuric acid*.

SULPHUR TRIOXIDE	combines with	WATER	to form	SULPHURIC ACID.

75. SULPHURIC ACID.

i. **Relative density of sulphuric acid.**—Make a mark upon a small beaker about one-third of the height from the bottom. Weigh the beaker. Pour distilled water into the beaker up to the mark. Weigh again and so determine the mass of the water. Pour out the water and carefully dry the beaker inside and out. Fill up to the mark with strong sulphuric acid, being careful to upset no acid on the pan of the balance. Weigh again and determine the mass of the acid. What is the relative density of the acid? (See p. 21.)

ii. **Heat developed during dilution of sulphuric acid.**—Pour strong sulphuric acid into a graduated measuring jar with a spout. Place a measured quantity of water, say 250 c.c., in a jug or large beaker. Take the temperature of the water. Add 25 c.c. of the acid to the water, pouring it out in a continuous small stream (for if the acid splashes it will injure you or your clothes). Keep the water stirred with the thermometer all the time; read the highest temperature recorded by the thermometer. Similarly add a second 25 c.c. of acid and again read the temperature. Then add a third 25 c.c. of acid, always keeping the mixture stirred, and again read the temperature.

Water should never be poured into strong sulphuric acid because of this generation of heat.

iii. **Sulphuric acid has a strong affinity for water.**—(*a*) Into a small weighed beaker, or wide-mouthed bottle, put enough strong sulphuric acid to reach to about one-third of the height. Weigh

again and determine the mass of the acid. Stick a piece of gummed paper outside the beaker to mark the level of the acid. Leave the acid exposed to the air for a day and then weigh again. Notice the increase in mass and also that the level of the liquid is now above the paper. The increase in mass and volume is due to water absorbed from the air.

(b) Drop a little strong sulphuric acid on to (1) a piece of wood, (2) some rags, (3) a little white sugar. Notice in each case the charring which results; this is due to the absorption of water and separation of carbon.

iv. **Acid properties.**—(a) Pour a few drops of sulphuric acid into a large quantity of water in a beaker. Taste the water by first dipping in your finger and then applying it to the tip of your tongue.

(b) Test the water with a blue litmus paper.

(c) Place a little of a dilute solution of sodium hydrate in a beaker; test it with a red litmus paper. Now add, little by little, some of the acidified water. A point will be soon reached when the solution has no effect on litmus. The acid has *neutralised* the sodium hydrate. If the solution be evaporated nearly to dryness and allowed to stand crystals will be obtained, known as *sodium sulphate.*

v. **Action upon metals.**—Refer to Experiments 60. i. and 74. iv. Also try the action of dilute sulphuric acid on iron filings.

vi. **Test for sulphuric acid and soluble sulphates.**—To dilute sulphuric acid or a solution of any soluble sulphate, such for example as the sodium sulphate obtained in Experiment 75. iv. *c*, add a few drops of barium chloride or barium nitrate. Notice the dense white precipitate which is formed. The precipitate cannot be got rid of either by boiling or by the addition of acids.

Sulphuric acid.—Familiarly known as *oil of vitriol*, sulphuric acid is one of the most important and useful of chemical compounds. It is manufactured in enormous quantities, and used in the preparation of a large number of substances, such as artificial manures, salt cake, and other things, which are necessary in a variety of industries.

It is a heavy, oily liquid, which, when strongly heated, boils at 335° C., and gives off a quantity of choking, pungent, white fumes. It mixes with water in all proportions, and produces during the solution so much heat that the temperature may rise above 100° C.—the boiling point of pure water—so that care has to be taken when sulphuric acid and water are mixed. It absorbs moisture from the air or from moist gases, and on this account is very frequently used for drying gases (Expt. 71. i.), and, owing to the same affinity for water, it chars organic matter, such as wood, etc. Like most other strong acids, it burns the skin and destroys cloth, so that care must be always taken in its use.

Its action upon metals has been already studied: with some metals, *e.g.* zinc, it reacts when cold and dilute, liberating hydrogen and forming a *sulphate* of the metal; with others, *e.g.* copper, it has no action until heated, when it produces a *sulphate*, but with the liberation of *sulphur dioxide.*

With substances known as alkalies, of which sodium hydrate is a typical example, sulphuric acid also forms sulphates, that resulting from its action upon sodium hydrate being known as sodium sulphate.

CHIEF POINTS OF CHAPTER XX.

Sulphur is a brittle, yellow solid, which may easily be reduced to a fine powder. It is insoluble in water, but dissolves in carbon bisulphide. It melts at about 114° C. to a clear, yellow, mobile liquid, which, when poured into cold water, solidifies to ordinary yellow sulphur. On further heating the yellow liquid becomes darker in colour, and more viscid, until at about 250° C. it will not run out, even though the vessel containing it is inverted. At still higher temperatures the liquid again becomes thin and mobile and finally boils, evolving a dark orange-red vapour, which condenses either to an orange liquid or to a yellow powder. If the boiling sulphur be poured into cold water it solidifies to a solid resembling caoutchouc.

This elastic solid is called *plastic sulphur.* If left in contact with air it returns to ordinary sulphur in a few days without any change of mass. The yellow powder into which sulphur vapour condenses, without passing through an intermediate liquid state, is called *flowers of sulphur.* Ordinary commercial sulphur is called *roll sulphur.*

Crystalline sulphur.—The crystals left when a solution of sulphur in carbon bisulphide is allowed to evaporate have an octahedral form. Those obtained from melted sulphur are needle-like, and called prismatic. The prismatic sulphur crystals will, if left alone, gradually change back to the octahedral variety.

Allotropy is the property some elements, like sulphur, possess of existing in different forms which are known as *allotropic forms.* The chief allotropic forms of sulphur are the octahedral, prismatic, and plastic.

Oxides of sulphur.—*Sulphur dioxide* is formed when sulphur burns in air or oxygen. It is also given off when copper is heated with strong sulphuric acid. It is a gas with a pungent smell, which does not burn nor support combustion, and has the power of bleaching vegetable colours. It dissolves in water to form *sulphurous acid.*

Sulphur trioxide.—By suitable means sulphur dioxide can be made to combine with more oxygen to form a higher oxide known as sulphur trioxide. This oxide dissolves in water, with a hissing noise accompanied by the evolution of much heat, to form *sulphuric acid.*

Sulphuric acid is a heavy, oily liquid, which boils at 335° C., giving off choking, pungent, white fumes. It mixes with water in

all proportions with the evolution of much heat. It absorbs moisture very readily, and is consequently used for drying gases. For the same reason it chars any organic substance it comes in contact with. Sulphuric acid forms salts called *sulphates.*

EXERCISES ON CHAPTER XX.

1. Describe the changes which sulphur undergoes when heated.

2. What is plastic sulphur, and how is it obtained? How would you prove it consists solely of sulphur?

3. Describe two methods for obtaining crystals of sulphur. What differences are there in the crystals so obtained?

4. What happens when sulphur burns? By what other method can you obtain the product formed?

5. Give an account of the properties of sulphur dioxide.

6. Describe the appearances and properties of sulphur trioxide. How is it obtained, and what is its action on water?

7. What are "flowers" of sulphur, and how is sulphur obtained in this condition?

8. What do we mean by allotropic forms? Give examples.

9. How would you show that the gas formed when brimstone burns in air has the power of bleaching vegetable colours?

10. How is the element sulphur found naturally? Name as many chemical compounds as you are acquainted with, known as minerals, which contain sulphur as one of their elements.

CHAPTER XXI.

LAWS OF CHEMICAL COMBINATION. CHEMICAL FORMULAE.

76. LAW OF DEFINITE PROPORTIONS.

i. **Magnesium and oxygen combine in definite proportions.**—(*a*) Repeat Experiment 54. i. *b*, but separately weigh the empty crucible with its lid, and then when the pieces of clean magnesium ribbon (or magnesium powder) are in it. In this way determine the mass of the magnesium. Occasionally slightly raise the lid of the crucible so that more air may enter but no fumes escape. Continue the heating until all the magnesium is changed into white oxide. When the crucible is cold, weigh again; subtract the mass of the crucible and lid, and so determine the mass of the magnesium oxide. Calculate the amount of oxygen with which one gram of magnesium should combine.

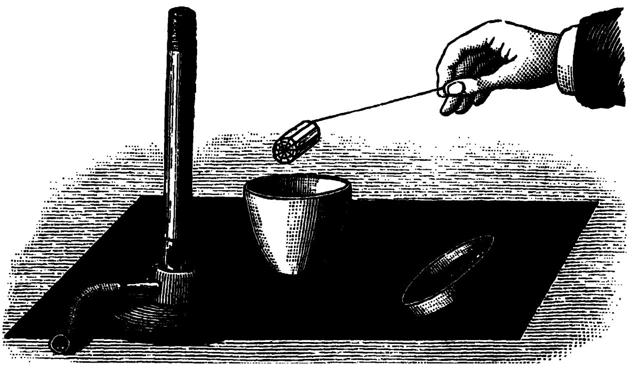

Fig. 197.—Burning a filter paper on which a precipitate has been collected, as in Expt. 76. ii.

(*b*) Repeat the last experiment with another mass of magnesium, and again calculate from your results the amount of oxygen with which one gram should combine. The result should be the same as before.

ii. **The composition of magnesium oxide is the same however it is made.**—Weigh out the same mass of clean magnesium ribbon as was used in Experiment 76. i. Transfer it to a clean beaker, and dissolve it in dilute sulphuric acid. When the solution is complete add a strong solution of sodium carbonate until the liquid turns a red litmus paper blue. Filter the solution with the white precipitate in it. When all the precipitate has in this way been transferred to the filter paper, wash it once or twice by nearly filling the filter paper in the funnel with distilled water. Transfer the funnel and paper to a water-oven and leave it until quite dry. Take the paper out of the funnel and roll it up, taking care to lose none of the powder. Wind a platinum wire round it, and then, holding it over a weighed crucible placed on a piece of black paper, burn the paper as shown in Fig. 197. Shake the powder into the crucible, sweeping any dust which has fallen from the wire on to the black paper into the crucible with a dry camel-hair brush. Weigh the crucible and its contents; subtract the mass of the crucible and observe that the mass of the magnesium oxide (for such the white powder is) is the same as obtained by burning the same mass of magnesium in Experiment 76. i.

iii. **Oxygen and hydrogen combine in definite proportions to form water.**—Refer to Experiment 62. ii., and, if necessary, repeat it. Read what is said about the Experiment on p. 239.

Laws of chemical combination.—Chemical action between different substances does not take place in a haphazard fashion. Experience has taught chemists that certain rules, or laws, regulate all chemical changes, and it is of the highest importance that you should know some of these laws. One, *the indestructibility of matter*, or *the conservation of mass*, you have already studied. Experiments 54. i. to 54. v. have shown you that matter cannot be destroyed. However profound the changes which may take place in the properties and composition of substances, the total mass of the compounds, or elements, taking part in the changes remains unaltered. The amount of matter in the universe is the same at this moment as it has always been.

Law of definite proportions.—*Chemical combination always takes place between definite masses of substances.* This statement is believed to be a fact by all chemists. Only a certain number of instances of chemical combination have been examined—a very large number, it is true. Though the word "always" is used in stating the law, it will never be possible to say that all cases of chemical combination have been investigated. But each one of the numerous chemical changes which have been studied shows the same definiteness in the proportions

of the substances taking part. In the absence of any exceptions to the rule among the many experiments which have been made to test the truth of the statement it is permissible to speak of it as a fact, or law of chemical combination.

From the experiments with magnesium just described it is easy to understand exactly what the law means. When a certain mass of magnesium is converted into magnesium oxide, the change is the result of the combination of the metal with a certain amount (never more, never less) of oxygen. Or, the mass of magnesium oxide which can be obtained from a certain definite mass of magnesium is always the same, however the change is brought about. The piece of magnesium may be made to combine with oxygen directly, by burning it in air or in pure oxygen; but the amount of magnesium oxide formed will be just the same as if the magnesium is first converted into magnesium sulphate by dissolving it in dilute sulphuric acid, then changing the sulphate into magnesium carbonate by adding sodium carbonate, and finally breaking the magnesium carbonate up by heating it strongly, and so leaving the oxide behind. Similarly, when hydrogen burns in air, as in Experiment 60. iii., or is made to combine with the oxygen of copper oxide, as in Experiment 62. ii., there is a definite proportion between the masses of hydrogen and oxygen which combine to form water. Whatever the circumstances of the experiments, if water is the result of the chemical combination, one part of hydrogen by mass unites with eight parts by mass of oxygen to form nine parts by mass of water. Water, wherever obtained, always contains the same proportions by mass of its constituents.

This leads to another way of stating the first law of chemical combination. It may be expressed thus: *Every chemical compound always contains the same elements united together in the same proportions by mass.* For example, 100 parts by mass of common salt always contain 39·3 parts by mass of sodium combined with 60·7 parts by mass of chlorine; and 100 parts by mass of potassium chlorate always contain 31·87 parts by mass of potassium, 28·90 parts of chlorine, and 39·23 parts of oxygen.

Law of multiple proportions.—Sometimes two elements unite together in more than one proportion by mass. But in such cases distinct compounds, each possessed of its own properties, are formed. As has been already learnt, two

oxides of sulphur are known—sulphur dioxide and sulphur trioxide. Both these compounds contain only sulphur and oxygen, but the proportion in which the elements are united together is different in the two compounds.

According to the law of definite proportions sulphur dioxide always contains the same amounts of sulphur and oxygen, and these are one part by mass of sulphur combined with one part by mass of oxygen. Sulphur trioxide always contains one part by mass of sulphur united with one and a half parts by mass of oxygen.

But there is another important relation brought to light by comparing the amount of oxygen which combines with sulphur to form sulphur dioxide with the amount of oxygen which combines with sulphur to form sulphur trioxide. Notice:

In sulphur dioxide 1 part by mass of sulphur combines with 1 part by mass of oxygen.

In sulphur trioxide 1 part by mass of sulphur combines with $1\frac{1}{2}$ parts by mass of oxygen.

But $1 : 1\frac{1}{2}$ is in the same proportion as $2 : 3$, which is a very simple ratio.

Nitrogen and oxygen combine together in five different proportions to form five different oxides, each with its own characteristic properties. These oxides, with the proportion of oxygen and nitrogen they contain, are:

Name of Compound.	Composition by Mass.	Ratio of mass of Oxygen combined with same mass of Nitrogen.
Nitrogen monoxide,	28 parts nitrogen with 16 parts oxygen,	1
Nitrogen dioxide,	28 ,, ,, ,, 32 ,, ,,	2
Nitrogen trioxide,	28 ,, ,, ,, 48 ,, ,,	3
Nitrogen tetroxide,	28 ,, ,, ,, 64 ,, ,,	4
Nitrogen pentoxide,	28 ,, ,, ,, 80 ,, ,,	5

The composition of the five oxides when shown in the above tabular form reveals the important fact that the amount by mass of oxygen which combines with the same mass of nitrogen increases in a fixed proportion. The amounts of oxygen in the different oxides which combine with the same 28 parts by mass of nitrogen are respectively, twice, three times, four times, and five times that in the simplest compound, nitrogen monoxide.

Carbon, again, forms two compounds with oxygen. Carbon monoxide, containing 12 parts by mass of carbon combined with

16 parts by mass of oxygen; and carbon dioxide, containing 12 parts by mass of carbon combined with 32 parts by mass of oxygen. Or, the amounts of oxygen in the two compounds combining with the same mass of carbon are in the proportion of 1 to 2.

In all cases where two elements combine in different proportions to form different compounds with different properties, if the amounts of the second element which combine with a fixed mass of the first be examined they are always found to bear some simple relation to one another, similar to the cases which have been studied above. This fact is known as the *law of multiple proportions*, which may be stated thus:

If two elements, A and B, combine in different proportions, the relative masses of B, which combine with any fixed mass of A, bear a simple ratio to one another.

Atoms and molecules.—The explanation which chemists offer to account for the above laws of chemical combination, and other facts concerning the composition of chemical substances, is that known as *The Atomic Theory*. John Dalton of Manchester, in the early part of this century, revived an old notion of the early Greek philosophers, and by his experiments laid the foundations of the atomic theory as it is understood by modern chemists. Matter cannot be divided and subdivided indefinitely. A point would be reached when a further subdivision would be accompanied by an alteration of the properties of the substance due to its decomposition into the elements of which it is composed. For instance, given a quantity of the red oxide of mercury, if it were divided into two portions and again and again into two, by and by, a further subdivision would mean resolving the red oxide of mercury into the elements oxygen and mercury.

The smallest particle of a compound which can have a separate existence is called a *molecule*. The molecule of a compound can be subdivided into smaller parts called *atoms*. Atoms are indivisible. Half or any other part of an atom cannot exist. And free atoms are not common; most frequently several atoms combine together to form a molecule. If all the atoms in a molecule are of the same kind, the substance is an element; if the atoms in a molecule are of different kinds, the substance is a compound. *Molecules are, therefore, the smallest particles of matter which can have a separate existence.*

Chemical symbols.—For the purpose of briefly expressing chemical changes chemists have adopted a system of representing elements by letters called *symbols*. In accordance with the laws of chemical combination these symbols are united to form *chemical formulae*, each formula consisting of certain symbols representing the amount and kind of the elements present in a compound.

These symbols are usually the first letters of the names of the element; sometimes the first letters of the Latin names of the element; and often the characteristic letters of the English or Latin name.

Argon (A), Boron (B), Carbon (C), Fluorine (F), Hydrogen (H), Iodine (I), Nitrogen (N), Oxygen (O), Phosphorus (P), Sulphur (S) are elements represented by the first letter of the English name. Potassium (Kalium) K, is an instance of an element represented by the first letter of its Latin name.

Aluminium (Al), Arsenic (As), Barium (Ba), Bismuth (Bi), Bromine (Br), Calcium (Ca), Chlorine (Cl), Magnesium (Mg), Platinum (Pt), Silicon (Si), Zinc (Zn), are instances of elements represented by the characteristic letters of their English names; while Antimony (Stibium) Sb, Gold (Aurum) Au, Iron (Ferrum) Fe, Lead (Plumbum) Pb, Mercury (Hydrargyrum) Hg, Sodium (Natrium) Na, are examples of elements the symbols for which are the characteristic letters of their Latin names.

Formulae of compounds.—To understand the reasoning upon which the formulae assigned to different compounds depends, it is necessary to state a law first enunciated by the Italian chemist Avogadro, though the proofs of the law and its full significance may not be fully understood by you until you have gone further into your study of chemistry. Avogadro's law states that *equal volumes of all gases, under similar conditions of temperature and pressure, contain equal numbers of molecules.* This law and the other facts which have been learnt about chemical symbols may now be applied to finding the formulae of certain simple chemical compounds.

Hydrochloric acid gas.—You have already learnt (p. 271) that 1 volume of hydrogen combines with 1 volume of chlorine to form 2 volumes of hydrochloric acid gas. Or, making use of Avogadro's law, it may be said that a certain number of molecules of hydrogen combine with the same number of molecules of chlorine to form twice the number of molecules of hydro-

chloric acid gas. This is equivalent to saying that one molecule of hydrogen combines with one molecule of chlorine to form two molecules of hydrochloric acid gas.

But hydrochloric acid gas must always contain both hydrogen and chlorine; therefore the molecule of this gas contains both elements, and must contain *at least* an atom of each, since this is the smallest amount which can exist, and two molecules of hydrochloric acid gas must contain at least two atoms of hydrogen and two atoms of chlorine. But one molecule each of hydrogen and chlorine give rise to two molecules of hydrochloric acid gas, and consequently we are led to the result that all molecules of hydrogen and chlorine each contain *at least* two atoms. This is, in reality, the number of atoms in each molecule of these elements; in fact, the general rule is that *the molecule of a gaseous element contains two atoms.*

The formula of hydrochloric acid gas is consequently written HCl, and it signifies that each molecule of the gas contains one atom of hydrogen and one atom of chlorine.

Formula for water.—Two volumes of hydrogen combine with one volume of oxygen to form two volumes of steam (p. 271). Therefore, applying Avogadro's law, it may be stated that two molecules of hydrogen combine with one molecule of oxygen to form two molecules of steam. It may further be added, in view of the last paragraph, that 4 *atoms* of hydrogen combine with 2 *atoms* of oxygen to form 2 molecules of steam; or, each molecule of steam contains 2 atoms of hydrogen and 1 atom of hydrogen. The molecule of steam may, therefore, be represented by H_2O.

Examples of chemical formulae.—It will not be out of place now to give the chemical formulae of some of the common compounds which have been mentioned by name in the foregoing chapters. Those compounds containing only two elements are known as *binary* compounds, and as these are the simplest they are mentioned first in the following lists:

BINARY COMPOUNDS.

Calcium chloride, $CaCl_2$.
Calcium oxide (lime), CaO
Carbon dioxide, CO_2.
Carbon bisulphide, CS_2.
Copper chloride, $CuCl_2$.
Copper oxide, CuO.
Iron chloride, $FeCl_2$.
Iron pyrites, FeS_2.
Lead sulphide (galena), PbS.
Magnesium oxide, MgO.
Manganese dioxide, MnO_2.
Mercury oxide (red), HgO.

Phosphorus pentoxide, P_2O_5.	Sulphur trioxide, SO_3.
Potassium chloride, KCl.	Sulphuretted hydrogen, SH_2.
Sodium chloride, $NaCl$.	Zinc chloride, $ZnCl_2$.
Sodium oxide, Na_2O.	Zinc sulphide (blende), ZnS.
Sulphur dioxide, SO_2.	

OTHER COMPOUNDS.

Copper sulphate, $CuSO_4$.	Sodium hydrate, $NaHO$.
Calcium carbonate, $CaCO_3$.	Sodium sulphate, Na_2SO_4.
Calcium sulphate, $CaSO_4$.	Sulphuric acid, H_2SO_4.
Sodium carbonate, Na_2CO_3.	Zinc sulphate, $ZnSO_4$.

It must be remembered that each of these formulae stands for a molecule of the compound represented, and shows the number of atoms of each of the elements present in it. Thus, H_2SO_4 represents a molecule of sulphuric acid, which contains two atoms of hydrogen, one of sulphur, and four of oxygen, or seven atoms in all. Similar reasoning applies to the other cases. The formulae, moreover, shortly express the result of a series of experiments performed to ascertain the composition of the bodies—it is only after careful analysis that a chemist can decide upon the proper formula for a compound.

Atomic weights.—Experiment has shown that any volume of oxygen is 16 times as heavy as an equal volume of hydrogen at the same temperature and pressure. We consequently know, from Avogadro's law, that a molecule of oxygen is 16 times as heavy as a molecule of hydrogen. Since, moreover, the molecules of both gases each contain two atoms, we can say that an atom of oxygen is 16 times as heavy as an atom of hydrogen. If, now, the mass of an atom of hydrogen is taken as the unit, the mass of an atom of oxygen will be 16, which number is called the *atomic mass or atomic weight* of oxygen. When equal volumes of chlorine and hydrogen, under the same conditions of temperature and pressure, are weighed, the chlorine is found to be 35½ times as heavy as the hydrogen, and consequently, by similar reasoning to that used in the case of oxygen, it may be said that the atomic weight of chlorine is 35½.

The atomic weight of an element is the ratio of the mass of its atom to the mass of an atom of hydrogen.

The determination of an atomic weight is, however, not always so simple a process as may appear from the foregoing description. It is not always possible to weigh the element in the form of a gas and compare it directly with the weight of

an equal volume of hydrogen. Chemists use many other methods, but a description of them would be out of place here A list of the elements with their symbols and atomic weights is given at the end of the Chemistry part of this book (p. 316).

Chemical equations.—By means of chemical formulae it is possible to represent in a concise form any chemical change when its nature is fully understood. In this way much verbal description is saved, and, in addition to this, chemists are able to study the interaction of chemical substances in a very convenient manner. The compounds taking part *in* the chemical change are placed on the left-hand side of the equation, and those which result *from* the change on the right. To illustrate the use made of formulae and equations in chemistry consider a chemical change which is already familiar to you, viz., that which occurs when zinc acts upon dilute sulphuric acid. You already know that hydrogen gas is given off and zinc sulphate is left in the flask. The chemical equation representing the change is

$$\underset{\text{Zinc}}{Zn} \underset{\text{combines with}}{+} \underset{\text{Sulphuric acid}}{H_2SO_4} \underset{\text{to form}}{=} \underset{\text{Zinc sulphate}}{ZnSO_4} \underset{\text{and}}{+} \underset{\text{Hydrogen.}}{H_2}$$

It is very important to give the right meaning to the "equality sign" which joins the two sides of the equation. It simply represents the fact, already studied, of the indestructibility of matter. The total mass of all the substances represented on the left-hand side of the equation, those, that is, that are caused to act on one another, is the same as the sum of the masses of all the substances formed by the chemical change. The equality refers only to mass. There is no other equality about a chemical equation.

But this is not all that a chemical equation means. Zn stands for an atom of zinc, which is 65 times as heavy as an atom of hydrogen. H_2SO_4 stands for a molecule of sulphuric acid, which, as the symbol shows, contains two atoms of hydrogen, weighing twice as much as one atom; one atom of sulphur, the atomic weight of which is 32; and four atoms of oxygen with an atomic weight of 16. The weight of the molecule of sulphuric acid, or its molecular weight, can be got by addition. Thus:

$$\left.\begin{array}{l} H_2 = 1 \times 2 = 2 \\ S = 32 \quad\;\; = 32 \\ O_4 = 16 \times 4 = 64 \end{array}\right\} = 98$$

The molecular weights of the other compounds can be obtained in a similar manner. If the equation be written again with the numbers underneath we shall be able to state quite definitely its full meaning :

$$\underset{65}{Zn} + \underset{\underbrace{2+32+64}_{98}}{H_2SO_4} = \underset{\underbrace{65+32+64}_{161}}{ZnSO_4} + \underset{2}{H_2}$$

If 65 parts by mass of zinc act upon 98 parts by mass of sulphuric acid, 161 parts by mass of zinc sulphate are formed, and 2 parts by mass of hydrogen are given off in the form of a gas. The equation means all this even though the numbers be not inserted. To rightly express the meaning of any chemical equation which may be placed before you, it will be necessary to refer to the table of atomic weights at the end of Chapter XXIII. and to find the molecular weight of the substances formed. You will do well to add the numbers to the following equations and write out their full meaning in a similar way to the above example.

Examples of Chemical Equations.—

Preparation of oxygen (p. 219) :

$$\underset{\text{Red oxide of mercury.}}{HgO} = \underset{\text{Mercury.}}{Hg} + \underset{\text{Oxygen.}}{O}$$

$$\underset{\text{Potassium chlorate.}}{KClO_3} = \underset{\text{Potassium chloride.}}{KCl} + \underset{\text{Oxygen.}}{3O}$$

Combustion in oxygen (p. 222) :

$$\underset{\text{Carbon.}}{C} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Carbon dioxide.}}{CO_2}$$

$$\underset{\text{Phosphorus.}}{P_2} + \underset{\text{Oxygen.}}{O_5} = \underset{\text{Phosphorus pentoxide.}}{P_2O_5}$$

$$\underset{\text{Sulphur.}}{S} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Sulphur dioxide.}}{SO_2}$$

$$\underset{\text{Magnesium.}}{Mg} + \underset{\text{Oxygen.}}{O} = \underset{\text{Magnesium oxide.}}{MgO}$$

Preparation of hydrogen (p. 228) :

Fe_3	+	$4H_2O$	=	Fe_3O_4	+	$4H_2$
Iron.		Steam.		Oxide of iron.		Hydrogen.

Na	+	H_2O	=	NaHO	+	H
Sodium.		Water.		Sodium hydrate.		Hydrogen.

Burning of hydrogen (p. 235) :

H_2	+	O	=	H_2O
Hydrogen.		Oxygen.		Water.

Passing hydrogen over heated black copper oxide (p. 238) :

CuO	+	H_2	=	H_2O	+	Cu
Copper oxide.		Hydrogen.		Water.		Copper.

Preparation of hydrochloric acid (p. 264) :

NaCl	+	H_2SO_4	=	$NaHSO_4$	+	HCl
Sodium chloride.		Sulphuric acid.		Sodium hydrogen sulphate.		Hydrochloric acid.

NaCl	+	$NaHSO_4$	=	Na_2SO_4	+	HCl
				Sodium sulphate.		

Action of metals on hydrochloric acid (p. 268) :

Zn	+	2HCl	=	$ZnCl_2$	+	H_2
				Zinc chloride.		

Fe	+	2HCl	=	$FeCl_2$	+	H_2
				Chloride of iron.		

Preparation of chlorine (p. 268) :

MnO_2	+	4HCl	=	$MnCl_2$	+	$2H_2O$	+	Cl_2
Manganese dioxide.				Chloride of manganese.				Chlorine.

Preparation of sulphur dioxide (p. 277) :

Cu	+	$2H_2SO_4$	=	$CuSO_4$	+	$2H_2O$	+	SO_2
				Copper sulphate.				Sulphur dioxide.

To prevent misconception it should perhaps be pointed out that there is a difference in the value of the numbers in a chemical equation according to their position. In the last of

the above equations $2H_2SO_4$ occurs. The first larger 2 which precedes the symbol means the number of molecules of sulphuric acid represented in the equation, while the smaller 2 after and below the H means the number of atoms of hydrogen in a single molecule of sulphuric acid.

Combination by volume.—In dealing with the composition of hydrochloric acid gas (p. 271) and of steam (p. 237) by volume, attention has been directed to a simple relation existing between the volumes of the elementary gases which unite to form these compounds and the volume of the compound formed. It has been seen that

H	+	Cl	=	HCl
1 volume.		1 volume.		2 volumes.

H_2	+	O	=	H_2O
2 volumes.		1 volume.		2 volumes.

One volume of hydrogen (whether a litre, a pint, or any other volume) combines with one volume of chlorine to form two volumes of hydrochloric acid gas. Two volumes of hydrogen combine with one volume of oxygen to form two volumes of steam. Gay-Lussac was the first to notice the simple relation which exists in these and all other similar cases. He stated the fact by saying that *the volumes in which gaseous substances combine bear a simple relation to one another, and to the volume of the resulting compound.* This statement is generally referred to as the *Law of Gay-Lussac.*

CHIEF POINTS OF CHAPTER XXI.

Some laws of chemical combination.—The indestructibility of matter has already been studied in previous chapters.

Law of definite proportions.—Chemical combination always takes place between definite masses of substances.

Or, every chemical compound always contains the same elements united together in the same proportions by mass.

Law of multiple proportions.—If two elements, *A* and *B*, combine in different proportions, the relative masses of *B* which combine with any fixed mass of *A* bear a simple ratio to one another.

Atoms and molecules.—All matter is supposed to be built up of minute particles termed *atoms*. These atoms usually exist combined with other atoms to form *molecules*. The molecules of a compound are composed of different kinds of atoms united together. In an element the atoms are all of the same kind.

Chemical symbols.—Chemists represent the atoms of various elements by letters which are in general the first letter, or the characteristic letters, of the English or Latin name of an element. Thus, H represents the atom of hydrogen and Cl the atom of chlorine.

Avogadro's law.—Equal volumes of all gases, under similar conditions of temperature and pressure, contain equal numbers of molecules.

Chemical equations enable the chemist to represent chemical reactions by means of symbols. The formulæ of the reacting bodies are placed on the left-hand side of the equality sign, and those of the products on the right.

The **atomic weight** of an element is the ratio of the mass of its atom to the mass of an atom of hydrogen. Thus, when we say the atomic weight of chlorine is 35·5, we mean that the atom of chlorine is 35·5 times as heavy as the atom of hydrogen.

Combination by volume. *Law of Gay-Lussac.*—The volumes in which gaseous substances combine bear a simple relation to one another and to the volume of the resulting compound.

EXERCISES ON CHAPTER XXI.

1. What do you mean by the terms "atom" and "molecule"? Carefully point out the difference between them.

2. What is Avogadro's Law? Indicate the use of this law in the determination of the chemical symbol of a compound.

3. By what experiments and reasoning would you show that hydrochloric acid gas should be represented by the formula HCl?

4. What is a chemical equation? Write down the equations representing the changes in any three chemical operations you have seen, and give in words the exact meaning of the equation.

5. Write in words the *exact* meaning of the equation

$$2KClO_3 = 2KCl + 3O_2.$$

From this equation calculate the mass of oxygen obtainable from 100 grams of potassium chlorate.

6. Explain clearly why we represent the molecule of water by the formula H_2O.

7. "The molecule of hydrogen must contain at least two atoms." Justify this statement.

8. Write in words exactly what is meant by the chemical equation

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

$$(Zn = 65; S = 32; O = 16.)$$

9. Explain, with examples, (*a*) the law of definite proportions, (*b*) the law of multiple proportions.

10. Write the names of the following: HCl, H_2SO_4, $CaCO_3$, Na_2SO_4, and $ZnCl_2$.

11. Explain the meaning of the equality sign (=) in a chemical equation.

12. State and give an example of Gay-Lussac's law of volumes.

CHAPTER XXII.

NITRIC ACID. BASES AND SALTS.

77. NITRIC ACID.

i. **Preparation of nitric acid.**—Into a stoppered retort, such as is used in the distillation of water (p. 242), place 30 or 40 grams of small crystals of potassium nitrate (also known as nitre). Using a funnel, carefully introduce enough strong sulphuric acid to cover the nitre. Replace the stopper. Place the retort on a stand as shown in Fig. 182, and insert its neck in that of a flask which is continually kept cool by water, just as in the distillation of water. Gently heat the retort. Brown fumes are given off in abundance, and soon drops of a light yellow liquid are seen to fall into the receiving flask. When enough nitric acid has distilled over remove the laboratory burner, and while the materials in the retort are still liquid pour them, after removing the stopper, from the retort into an evaporating dish.

ii. **Properties of nitric acid.**—(*a*) Pour a drop or two of the nitric acid from the receiving flask into a small glass of water. Taste a drop of the water by dipping the tip of your finger into it and then applying the finger to your tongue.

(*b*) Test the water with a blue litmus paper. The paper is turned red.

(*c*) Pour a drop or two of the nitric acid from the receiving flask (Experiment 77. i.) on to a fragment of copper in a test-tube. Notice the brown fumes and the blue solution formed.

(*d*) Try the action of a little of the acid from the flask on a piece of cloth, and of a single drop on the palm of the hand. Notice the cloth is slowly destroyed and the skin is turned yellow.

iii. **Nitric acid easily gives up oxygen.**—Procure a clay tobacco pipe of the pattern known as a "church-warden," and by means of a retort-stand with a clip support it in the position shown in Fig. 198. Let its stem dip into a pneumatic trough in the manner the illustration makes clear. Heat the middle of the stem with a Bunsen burner until it is red-hot. When this is the case, drop strong nitric acid slowly into the bowl. You will notice that a colourless gas collects in the cylinder over the pneumatic trough. When a sufficient amount of the colourless gas has been obtained in the cylinder, lift the stem of the pipe out of water, and remove the

burner. Test the gas in the cylinder with a glowing splinter of wood. The gas is oxygen.

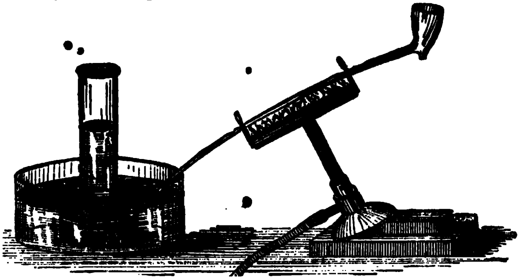

FIG. 198.—An experiment to show that nitric acid easily gives up oxygen.

Nitric acid.—One of the most important compounds with which chemists are familiar is an acid which has long been known under the name of *aqua fortis.* It is a compound of nitrogen with hydrogen and oxygen, and its constitution is briefly expressed by its symbol HNO_3. It can be prepared by synthesis (p. 237) from its constituent elements, but the experiment is rather one of theoretical interest than of practical importance. It is always prepared by distilling a nitrate with strong sulphuric acid. Either potassium nitrate (KNO_3), which is more familiarly known as "saltpetre" or "nitre," or sodium nitrate ($NaNO_3$), also called "Chili saltpetre," is generally employed. The latter salt is the cheaper and in addition yields a larger amount of nitric acid for a given expenditure of sulphuric acid, so that it is more commonly employed than ordinary saltpetre in the manufacture of nitric acid.

The changes which take place when potassium nitrate is distilled with sulphuric acid in a glass retort, as described in Experiment 77. i., may be most conveniently expressed by a chemical equation :

$$\underset{\text{Potassium nitrate.}}{KNO_3} + \underset{\text{Sulphuric acid.}}{H_2SO_4} = \underset{\text{Potassium hydrogen sulphate.}}{KHSO_4} + \underset{\text{Nitric acid.}}{HNO_3},$$

which shows that a double decomposition takes place. The potassium atom in the molecule of potassium nitrate is replaced by a hydrogen atom from the sulphuric acid, and in this way the potassium nitrate is changed into hydrogen nitrate or nitric

acid. At the same time one of the hydrogen atoms of the molecule of sulphuric acid is replaced by a potassium atom from the potassium nitrate, and the sulphuric acid, or hydrogen sulphate, is converted into hydrogen potassium sulphate.

In the manufacture of nitric acid on a large scale, however, greater heat is employed. This is possible because earthenware retorts replace the glass vessel of Experiment 77. i. In these circumstances the chemical change is taken a step further, as the following equation makes clear:

KNO_3	+	$KHSO_4$	=	K_2SO_4	+	HNO_3.
Potassium nitrate.		Potassium hydrogen sulphate.		Potassium sulphate.		Nitric acid.

A further quantity of nitric acid is, in this way, obtained from the same expenditure of sulphuric acid. The two steps in the chemical change can be represented in one chemical equation, which only shows the final products of the reaction:

$$2KNO_3 + H_2SO_4 = K_2SO_4 + 2HNO_3.$$

This may be more graphically written as follows, and the student by studying the rearrangements of the chemical symbols can obtain a good mental picture of the nature of the chemical changes:

$$\begin{matrix}H\\H\end{matrix}SO_4 + \begin{matrix}KNO_3\\KNO_3\end{matrix} = \begin{matrix}K\\K\end{matrix}SO_4 + \begin{matrix}HNO_3\\HNO_3\end{matrix}.$$

For practice the student should write out the equations which show the changes that take place when sodium nitrate is made use of instead of potassium nitrate.

Properties of nitric acid.—Nitric acid has certain properties associated with all acids. It has a sour taste and turns a blue litmus paper red. Other characteristics possessed by acids will be studied at the end of the present chapter.

When pure, nitric acid is colourless and gives off colourless fumes. But it is easily decomposed. When heated it gives off brown fumes. This happens slowly when the pure acid is placed in sunlight, a fact which accounts for the brown fumes above the liquid in bottles of nitric acid which have been kept for some time.

It is a very powerful acid, hence its name, *aqua fortis*, which dates from the time when all liquids were considered to be some kind of water. It destroys organic materials, like wood and cloth. It acts violently on most metals, like copper in Experiment 77. ii. *c*. Gold and platinum are exceptions, for nitric acid

has no action upon them. It very readily gives up some of the oxygen, of which it contains large quantities. Its great activity is due to the readiness of giving up oxygen, and for this reason it is called an *oxidiser*.

Not only does nitric acid give up oxygen when it is passed over a heated surface, as in Experiment 77. iii., but also in coming into contact with different substances. For example, if strong nitric acid be dropped upon heated sawdust, the organic material catches on fire. Or, if a stick of charcoal be made red hot and plunged beneath the surface of some strong nitric acid, it will burn brilliantly at the expense of the oxygen in the nitric acid.

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78. BASES AND SALTS.

i. **Examples of bases.**—(*a*) Place a small piece of potassium in water, and afterwards evaporate the liquid to dryness. Examine the solid produced, and compare it with caustic potash. Place a piece of moistened red litmus in contact with the solid. It is turned blue.

(*b*) Place a small piece of sodium in an evaporating dish containing water. An alkaline solution of sodium hydrate or caustic soda, which will consequently turn red litmus blue, is thus produced.

(*c*) Burn some magnesium and collect the white solid formed. Observe that it is a white powder insoluble in water, which glows when strongly heated, but does not undergo any chemical change.

Place a little of the powder on a moistened red litmus paper and observe the latter is turned blue.

(*d*) Examine a piece of lime. Note its effect on litmus, its slight solubility, action of heat, etc.

ii. **Preparation of salts.**—(*a*) *Sodium chloride.*—Make a solution of sodium hydrate, as in Expt. 78. i. *b*, or by dissolving caustic soda in water. To a portion of the solution in an evaporating basin add dilute hydrochloric acid, drop by drop, until the solution has no effect upon either a red or blue litmus paper. The solution is then said to be neutral. Gently evaporate the solution on a sand bath until a dry white residue is left. Then, by tasting the solid, satisfy yourself that it is common salt, or sodium chloride.

(*b*) *Sodium sulphate.*—Repeat the last experiment, substituting dilute sulphuric acid. In this way obtain sodium sulphate.

(*c*) *Sodium nitrate.*—Similarly perform the experiment, using dilute nitric acid. Sodium nitrate will be obtained.

Acids.—Hydrochloric, sulphuric, and nitric acids have now been studied, and it is necessary here to consider what characters these three compounds, so dissimilar in many of their properties, have in common, which leads chemists to call them all *acids*. The experiments described from time to time

have shown that the three compounds all have a sour taste, and that they all possess the power of turning a blue litmus paper red. These two properties are possessed by all acids. In addition, moreover, *all acids contain hydrogen*, which can, in suitable circumstances, be replaced by a metal. The conditions under which this substitution takes place will be understood better as the chapter proceeds, but it may be said at once that the metal may itself turn out the hydrogen by acting on the acid directly. An example of this is afforded by the preparation of hydrogen by acting on sulphuric acid with zinc. Or, the hydrogen of the acid may be replaced by the metal in a compound like caustic soda (sodium hydrate), or lime (calcium oxide). These facts may be collected together in the form of a definition of an acid. Thus:

An acid is a chemical compound with a sour taste, which has the power of turning blue litmus red. It always contains hydrogen, which can be replaced by a metal, either directly, or by the action of an oxide, or hydroxide of a metal upon it.

Bases and salts.—Another class of compounds, of which sodium hydrate and lime may be taken as typical examples, all possess properties of an opposite character to those which distinguish acids. They all have the power of destroying, or *neutralising*, the properties of an acid. These compounds are called *bases*. Some, such as caustic soda and caustic potash, are *soluble in water*, and are called *alkalies*. A solution of ammonia in water behaves like the two soluble bases mentioned, and is also classed with the alkalies.

Bases are always oxides or compounds of a metal with oxygen and hydrogen, known as *hydrates*, or, better, *hydroxides*. When added to an acid, the metal of the base replaces the hydrogen of the acid forming a *salt*. This is a fact of great importance. We may write it in the form of an equation:

A Base + An Acid = A Salt + Water.

This equation provides a definition of a base. It may be stated that:

A base is an oxide or a hydroxide of a metal, capable of neutralising an acid with the formation of a salt and water.

The equation, too, also furnishes a convenient definition of a salt, for it enables the statement to be made, that:

A salt is a neutral chemical compound formed by acting upon an acid with a base, in this way replacing the hydrogen of the acid with the metal.

Formation of salts.—The manufacture of salts by neutralising acids is a very important part of chemistry. More than this, the representation of the changes which occur provides such a valuable exercise in the use of chemical equations that several instances are here inserted.

Let us first represent the changes which take place when sodium chloride, sodium nitrate, and sodium sulphate are prepared by laboratory methods :

Base.		*Acid.*		*Salt.*		*Water.*
$NaOH$ Sodium hydroxide.	+	HCl	=	$NaCl$ Sodium chloride.	+	H_2O
$NaOH$	+	HNO_3	=	$NaNO_3$ Sodium nitrate.	+	H_2O
$NaOH$	+	H_2SO_4	=	$NaHSO_4$ Sodium hydrogen sulphate.	+	H_2O
$2NaOH$	+	H_2SO_4	=	Na_2SO_4 Disodium sulphate.	+	$2H_2O$.

The following equations similarly represent the formation of other familiar salts from a typical oxide, and the student is recommended to make himself familiar with the chemical changes which the equations symbolise :

Base.		*Acid.*		*Salt.*		*Water.*
CaO Lime or calcium oxide.	+	$2HCl$	=	$CaCl_2$ Calcium chloride.	+	H_2O
CaO	+	$2HNO_3$	=	$Ca(NO_3)_2$ Calcium nitrate.	+	H_2O
CaO	+	H_2SO_4	=	$CaSO_4$ Calcium sulphate.	+	H_2O.

Acid salts.—The equations representing the action of sodium hydroxide on sulphuric acid reveal another fact about salts. When an acid contains two atoms of hydrogen, capable of being replaced by a metal, it is possible to obtain two classes of salts. The hydrogen of the acid can be replaced in steps. Thus :

$$NaOH + {}^{H}_{H}SO_4 = {}^{Na}_{H}SO_4 + H_2O.$$

Sodium hydrogen sulphate.

When sodium hydrogen sulphate is tested with a blue litmus paper, the paper is reddened, showing that the properties of the acid have not been completely neutralised. For this reason the sodium hydrogen sulphate is often called *acid sodium sulphate.* If the acid sodium sulphate is acted upon with a further quantity of sodium hydroxide, the other atom of hydrogen is replaced by sodium. Thus :

$$NaOH + {}^{Na}_{H}SO_4 = {}^{Na}_{Na}SO_4 + H_2O.$$

Disodium sulphate.

Disodium sulphate has no action upon blue or red litmus, and is often spoken of as *neutral sodium sulphate.* Acids which, like hydrochloric and nitric acids, have only one atom of displaceable hydrogen in their molecules are called *monobasic* acids. Those, like sulphuric acid, are called *dibasic.*

Numerical considerations.—A given quantity of a base can only neutralise a definite quantity of the acid upon which it acts. It is necessary to examine and understand this fact. As an example, take the formation of sodium chloride in Experiment 78. ii. *a.*

$$\underset{(23+16+1=40)}{NaOH} + \underset{(1+35\frac{1}{2}=36\frac{1}{2})}{HCl} = \underset{(23+35\frac{1}{2}=58\frac{1}{2})}{NaCl} + \underset{(2+16=18)}{H_2O.}$$

The equation shows that 40 parts by mass of sodium hydroxide can neutralise $36\frac{1}{2}$ parts by mass of hydrochloric acid, and that $58\frac{1}{2}$ parts of sodium chloride are in this way obtained. This proportion is always maintained. One part by mass of the caustic soda can neutralise $\frac{73}{80}$ part by mass of the hydrochloric acid, never more and never less, and at the same time 1·17 parts of sodium chloride are prepared. These considerations form the basis of what is known as *volumetric analysis*, and the student will do well to study them carefully.

CHIEF POINTS OF CHAPTER XXII.

Nitric acid, HNO_3, sometimes called *aqua fortis*, is prepared by distilling potassium nitrate (KNO_3) or sodium nitrate ($NaNO_3$) with strong sulphuric acid.

Being an acid it has a sour taste and turns a blue litmus paper red. It is colourless when pure and is easily decomposed when heated. It acts violently on most metals. Its great activity is due to the readiness with which it gives up oxygen.

An acid is a chemical compound with a sour taste which has the power of turning blue litmus red. It always contains hydrogen,

which can be replaced by a metal either directly or by the action of an oxide or hydroxide of a metal upon it.

A base is an oxide or hydroxide of a metal capable of neutralising an acid with the formation of a *salt* and *water*.

A salt is a neutral chemical compound formed by the action of an acid on a base; in this way the hydrogen of the acid is replaced by a metal.

When the replacement of the hydrogen of the acid is only partial, an *acid salt* is formed.

EXERCISES ON CHAPTER XXII.

1. You are provided with some nitre and strong sulphuric acid, describe fully how you would proceed to prepare a specimen of nitric acid.
2. Why is nitric acid said to be an oxidiser? Describe an experiment to show its oxidising power.
3. Write equations to explain what happens when sodium nitrate and strong sulphuric acid are distilled together.
4. Using nitric acid as an example describe three experiments which show the characteristic properties of acids.
5. Write the names and symbols of three acids, three bases, and three salts.
6. Give the symbols for lime, sulphuric acid, zinc sulphate, caustic soda, spirits of salt, aqua fortis, and saltpetre.
7. Arrange the compounds named in Question 6 in three columns, distinguishing acids, bases, and salts.
8. How many kinds of salts can sulphuric acid form with potassium hydroxide? Give their names and symbols.
9. Explain the difference between (*a*) a monobasic and dibasic acid; (*b*) a neutral and an acid salt.
10. Describe fully the preparation of a typical salt.

CHAPTER XXIII.

SOME COMMON METALS.

79. GENERAL CHARACTERS OF METALS.

i. **Some familiar metals.**—(*a*) Examine specimens of lead, copper, iron, zinc, tin, silver, gold, sodium, and mercury. Notice that while most are heavy solids, sodium floats on water, and mercury is a liquid.

(*b*) Observe they are all opaque and possess a "metallic lustre." Compare with crystals of iodine to satisfy yourself that some non-metals possess a lustre. Examine a very thin sheet of gold between two glass plates; it is transparent.

ii. **All metals are not elements.**—Examine brass, gun-metal, pewter, German-silver, bronze, solder. These are *alloys* or mixtures of metallic elements. The metallic characters are not lost by mixing metals together.

Metallic elements.—Though most people have some idea of what a metal is, it is a somewhat difficult matter to exactly say what constitutes a metal. The fact is, that the elements cannot be sharply divided into two classes with all those that possess metallic properties in one division, and those in which such characteristics are absent in the other. It is an easy thing to enumerate the respects in which, say, the metal gold and the non-metal oxygen differ from one another, but there are many elements, like arsenic, which possess properties common to both typical metals and characteristic non-metals.

But, as a rule, metals may be said to possess the following properties, though the student must remember that exceptions are known to nearly every one of the statements.

Characters of metals.—1. Metals possess a peculiar lustre, which is commonly referred to as "metallic." But iodine and graphite, which are undoubtedly not metals, also have a lustre very like metals.

2. Metals are opaque. Yet gold can be rolled into sheets which are transparent to light.

3. Metals are very dense, or possess a high specific gravity. Sodium and potassium are unmistakable metals, yet they float upon water.

4. Metals, as a rule, are good conductors of heat and electricity.

5. Metals unite with oxygen, or with oxygen and hydrogen, to form bases, which neutralise acids.

Alloys.—All metals are not elements. Many of the familiar metals in common use are mixtures of metallic elements called *alloys*. When one of the metals present is mercury the alloy is known as an *amalgam*. The following table shows the metals present in some common alloys:

Alloy.	Metallic Elements Present.
Bell-metal, .	Copper and tin.
Brass, . .	Copper and zinc.
Bronze, . .	Copper and tin with some zinc and lead.
German-silver,	Copper and nickel.
Gun-metal, .	Copper and tin.
Pewter, . .	Tin and lead.
Solder, . .	Tin and lead.
Type-metal, .	Lead, tin, and antimony.

80. LEAD.

i. **Properties of lead.**—(*a*) Scrape a piece of lead and examine its metallic surface; incidentally notice that it is much softer than steel.

(*b*) By the method described on p. 24, determine the relative density of lead.

(*c*) Examine lead in the forms of sheets and wires. What properties must lead possess in order to be available in these forms?

ii. **Heating lead in air.**—(*a*) Melt lead in an iron spoon and pour the liquid metal into a mould made in sand.

(*b*) Melt more lead and keep the liquid metal stirred with an iron wire. Observe that it combines with the oxygen of the air to form yellow oxide of lead (litharge).

iii. **Lead obtained from its compounds.**—(*a*) Strongly heat some red lead on a piece of charcoal by means of a blow-pipe. Notice the globules of the metal which separate.

(*b*) Heat a mixture of lead oxide and powdered charcoal in a crucible by means of the flame of a foot blow-pipe. Again notice the separation of metallic lead.

iv. **Lead is soluble in nitric acid.**—Upon some fragments of lead in a test-tube pour some moderately strong nitric acid. Notice the brown fumes and the gradual solution of the lead. When the lead has dissolved, add water to the solution and gently evaporate on a sand-bath till nearly dry. Place on one side for a short time and notice the salt, lead nitrate, which separates in crystals.

Lead, Pb.—Lead has a bluish colour, which can be seen by examining an untarnished surface of the metal. The bright metal, however, soon tarnishes on exposure to air. It is $11\frac{1}{2}$ times as heavy as water. It is very malleable and fairly ductile. It melts at 326° C. into a silvery fluid, which can be easily cast in moulds. Melted lead combines with the oxygen of the air to form *litharge*, PbO, and if this be strongly heated it will combine with a further quantity of oxygen to form *red lead*, Pb_3O_4. Though it easily dissolves in nitric acid, forming lead nitrate $Pb(NO_3)_2$, hydrochloric acid and sulphuric acid have little, if any, action upon it.

In nature lead occurs combined with the element sulphur as the ore *galena*, which is lead sulphide, PbS. But many other ores are known.

The metal is made into sheets and pipes and extensively employed by the plumber. Alloyed with other metals it occurs as pewter, solder, and type-metal (p. 305).

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81. IRON.

i. **Properties of iron.**—(*a*) Determine the relative densities of steel, wrought-iron, and cast-iron by the methods described on p. 24.

(*b*) Recall and, if necessary, repeat the experiments dealing with the rusting of iron on p. 213, that concerning the burning of iron in oxygen on p. 223, and the action of acids upon it (p. 268).

(*c*) Revise what has been studied of the magnetic properties of the metal.

Iron, Fe.—Iron is by far the most important metal known to man. The discovery of how to obtain it from the minerals in which it occurs was probably the most valuable ever made. Though it is very abundant in nature, it is rarely found uncombined. It has been found in certain strange masses, called meteorites, which drop upon this planet from inter-stellar space. In the earth it is found combined with oxygen, forming oxides, as *magnetite* and *haematite*; as oxides combined with water in *limonite* and *gothite*; with sulphur, as the sulphides,

iron pyrites and *magnetic pyrites*; with carbon dioxide, as the carbonates, *clay iron-stone* and *chalybite*; and other less important ores.

Three kinds of iron.—Iron is known and used in three forms, *wrought-iron*, *cast-iron*, and *steel*. The first is almost the pure element, but cast-iron contains also varying amounts of carbon and silicon. Steel contains the same elements as cast-iron, but the amount of carbon is considerably smaller. The different uses to which these varieties of iron are put depends upon the difference in properties they possess.

Wrought-iron is very tough, and can easily be beaten out into plates. For those articles which are made by hammering the iron into shape, wrought-iron will evidently be used.

Cast-iron is, on the other hand, brittle and easily melted, and consequently is employed in all cases where the article is made by running the molten metal into moulds.

Steel has different properties according to the processes through which it has passed. If it has been heated and then cooled very quickly, it is extremely hard but very brittle; but if cautiously heated and cooled very much more slowly, it is no longer brittle but elastic. This latter process is called *tempering*. Another very important property which steel possesses is that it can be made into a magnet which will keep its magnetism for a very long time. All the magnetic needles used in telegraphing, and in electrical instruments of other kinds, are made of steel.

The relative densities of different kinds of iron are seen from the following table:

Steel, not hammered, ...	7·82
Iron, bar, ...	7·79
Iron, cast, ...	7·21

Oxides of iron.—Iron combines with oxygen in several proportions. The following table shows the proportions of the masses of iron and oxygen present in each case:

Ferrous oxide, FeO, . .	56	of iron with	16	of oxygen.
Ferric oxide, Fe_2O_3, . .	112	"	48	"
Tri-ferric tetroxide, Fe_3O_4, .	168	"	64	"

The first of these does not occur in nature as a mineral. It combines with acids forming the series of salts known to chemists as *ferrous* salts, one of which, *ferrous sulphate*, $FeSO_4$, is known naturally as the mineral *copperas*

The second, ferric oxide, is fairly abundant in nature. It constitutes the beautifully crystallised mineral *specular iron ore*, found in Elba. It also makes up the mineral *haematite*, which goes under the names of *kidney ore* and *pencil ore* in the Furness district of Lancashire, according to the shapes which it naturally assumes.

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82. COPPER.

i. **Properties of copper.**—(*a*) Examine copper in the form of bars, sheets, and wires. Notice its colour. From these varieties what properties of the metal can be deduced?

(*b*) Hold one end of a copper wire between your finger and thumb and put the other in the flame of a laboratory burner. You will soon be convinced that copper is a good conductor of heat.

ii. **Heating copper in air.**—(*a*) Heat a piece of sheet copper over the flame of a laboratory burner. Notice the formation of a black film. This is the black oxide of copper.

(*b*) Refer to the experiment on p. 238, and recall the action of hydrogen gas upon this black oxide when the latter is heated.

iii. **Action of copper on acids.**—Try the action of the common acids upon fragments of copper placed in test-tubes.

iv. **Iron can displace copper from its solutions.**—Into a solution of blue vitriol (copper sulphate) plunge the blade of a knife. Observe the deposition of copper on the blade. The iron of the knife passes into solution and takes the place of the copper.

v. **Alloys of copper.**—Examine specimens of brass, bronze, bell-metal, and gun-metal. Compare them with copper.

Copper, Cu.—Copper is a red metal which is found naturally in an uncombined or "native" condition. It also occurs as *ruby copper*, which is an oxide of the metal with the symbol Cu_2O; and more abundantly as *copper pyrites*, a compound of the metal with iron and sulphur. *Copper-glance and malachite* are also well known ores of copper.

Copper is hard and does not, when cold, change in dry air, though in moist air it slowly becomes covered with a green compound, due to the combination of the metal with carbon dioxide and water. When it is heated in the air copper combines with oxygen to form black oxide of copper, CuO.

The metal is nearly nine times as heavy as water. It is very ductile, and can be drawn out into very thin wires; its great malleability enables it to be rolled into very thin sheets, which are known as Dutch leaf. It is a good conductor of heat and of the electric current. Everybody is familiar with the use of

copper wires to conduct electric currents from one place to another.

Moderately strong nitric acid dissolves copper forming with it a blue salt, copper nitrate, $Cu(NO_3)_2$. Hydrochloric acid does not act upon the metal, nor does dilute sulphuric acid, but when copper is heated with strong sulphuric acid the metal is dissolved with the formation of copper sulphate, sulphur dioxide being evolved. These changes are represented in the following equation :

$$Cu + 2H_2SO_4 = CuSO_4 + 2H_2O + SO_2.$$

The alloys of copper are both numerous and useful. As an examination of the table on p. 305 shows, copper is mixed with tin in varying proportions to form bell-metal and gun-metal; with zinc to make brass; with nickel in the manufacture of German-silver; and with tin, zinc, and lead to produce bronze.

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83. MERCURY.

Properties of mercury.—(*a*) Determine the relative density of mercury by means of a density bottle as described on p. 19.

(*b*) Using the apparatus employed in the experiments described on p. 20, show that a column of mercury 1 inch high balances a column of water between 13 and 14 inches high. The relative density of mercury is consequently between 13 and 14.

(*c*) Satisfy yourself by trial, (1) an iron key floats on mercury, (2) mercury does not wet glass, (3) mercury adheres to clean zinc or copper, forming what is called an *amalgam*.

(*d*) Boil a little mercury in a test-tube and show that it is volatile. Some of the mercury condenses in tiny drops on the cool parts of the tube. Take care not to breathe any of the vapour.

(*e*) If necessary, repeat the experiment of heating red oxide of mercury (p. 219).

Mercury, Hg.—Mercury or quicksilver is the only metal which is liquid at ordinary temperatures. Its appearance is familiar to everyone from its frequent use in barometers and thermometers. It sometimes occurs pure in nature. Chiefly, however, it occurs in combination with sulphur as the mineral *cinnabar*, HgS, which is found in Spain, Hungary, Tuscany, and South America. If mercury is cooled to a temperature of $-40°$ C. it solidifies, and is then malleable. It is the heaviest liquid known, being $13\frac{1}{2}$ times as heavy as water.

If it be heated to a temperature of 315° C. and air be passed

over it, it combines with oxygen, forming red oxide of mercury. At ordinary temperatures the oxygen of the air has no action upon it and the metal does not tarnish by simple contact with air. It boils at 357°·5, and is converted into a transparent, colourless vapour, which is very poisonous. It dissolves many metals, *e.g.* zinc and copper, forming alloys known as *amalgams*.

Not only is it used in barometers and thermometers, but also in the manufacture of looking-glasses and in the laboratory, instead of water, over which to collect some gases soluble in water.

Hot concentrated sulphuric acid dissolves mercury, the action being exactly similar to that in the case of copper (p. 309). Nitric acid, too, dissolves it readily.

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84. SODIUM.

i. **Properties of sodium.**—(*a*) Notice that sodium is kept in naphtha or petroleum. This is because of its great affinity for oxygen; these liquids contain no oxygen, hence their use.

(*b*) Cut a piece of sodium and examine the metallic lustre of the freshly cut surface. The brightness soon disappears on exposure to air, due to the formation of sodium oxide.

ii. **Action of sodium on water.**—Repeat Experiment 59. ii. and recall what was there learnt.

iii. **Sodium is contained in common salt.**—Repeat Experiment 71. vi. and revise the reasoning on p. 267.

Sodium.—Sodium is an example of a metal lighter than water. Its relative density is only 0·97, and as was seen in preparing hydrogen from water by the action of sodium on this liquid (p. 229), the metal floats on water. When the piece of sodium comes into contact with the water it soon assumes a globular form and darts about the surface of the liquid in the most energetic manner, all the time combining with oxygen to form sodium oxide, Na_2O, which dissolves in the water; and at the same time hydrogen is evolved, and can, as the student has learnt, be collected by suitable means.

Because of the readiness with which sodium combines with oxygen it has to be kept under a liquid, in the composition of which oxygen takes no part, such as naphtha or petroleum.

Sodium also readily combines with chlorine (p. 267) to form sodium chloride, NaCl.

It forms with mercury an alloy known as sodium amalgam.

85. ZINC.

i. **Properties of zinc.**—(*a*) Examine some strips of zinc and make out as many properties as you can.

(*b*) Determine its relative density.

(*c*) Heat some pieces of zinc in an iron ladle and pour the liquid metal, drop by drop, into a bucket of water. The metal is cooled in the form of granulated zinc.

ii. **Action of acids upon zinc.**—(*a*) Re-read and, if necessary, repeat Experiment 60. i.

(*b*) Pour a little dilute nitric acid upon some fragments of zinc in a test-tube. Warm the solution. Filter and evaporate to dryness—zinc nitrate is thus obtained.

Zinc, Zn.—Zinc occurs in nature combined with sulphur in the form of zinc sulphide, ZnS, making the well-known ore *zinc blende*, or *black-jack*. The carbonate of zinc, $ZnCO_3$, occurs as the ore *calamine*. Zinc is a bluish-white metal about seven times as heavy as water. It does not readily combine with the oxygen of the air, and is extensively used to coat iron-plates to prevent their rusting. These sheets are known as *galvanised iron*. Zinc is also one of the constituents of brass. When zinc is strongly heated in air it readily combines with the oxygen, the combination being accompanied by a greenish flame.

As has been seen in studying hydrogen, zinc is easily dissolved by both sulphuric and hydrochloric acids, the hydrogen of the acid being evolved, and zinc sulphate, $ZnSO_4$, and zinc chloride, $ZnCl_2$, being formed.

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86. TIN.

i. **Properties of tin.**—(*a*) Examine a specimen of the pure metal. Notice its colour.

(*b*) Determine its relative density.

(*c*) Bend a piece of tin while holding it near the ear. Notice the crackling sound, called the "cry of tin."

ii. **Action of acids upon tin.**—(*a*) Upon pieces of granulated tin in separate test-tubes add (1) dilute, (2) concentrated hydrochloric acid. What happens? In the latter case a gas which burns is given off; what gas is this?

(*b*) Similarly try the action of dilute and sulphuric acid. The action is analogous to that with copper (Experiment 74. iv.).

(*c*) Concentrated nitric acid oxidises tin. Observe the white powder formed when strong nitric acid is warmed with metallic tin. The oxides of nitrogen remind one of the action of nitric acid upon copper and lead.

Tin.—Tin is a brittle, white metal with a relative density of about 7·3. Though fairly malleable, it is not ductile and cannot be made use of in the form of wires. The noise which is heard when a piece of tin is bent is due to its crystalline structure. The individual crystals rubbing against one another during the bending cause the crackling noise.

Tin occurs in nature chiefly in combination with oxygen in the form of *tin-stone*, SnO_2, being abundant in Cornwall and the Scilly Isles.

Though it combines with the oxygen of the air when it is melted by the application of heat, no such combination takes place at ordinary temperatures. Tin is in consequence extensively employed to protect iron from the action of the oxygen of the air. Thin iron plates are dipped into molten tin, and in this way converted into *tin-plate.*

Concentrated hydrochloric acid dissolves tin with the evolution of hydrogen :

$$Sn + 2HCl = H_2 + SnCl_2$$

Strong sulphuric acid also dissolves the metal, but in this case sulphur dioxide is given off copiously. Concentrated nitric acid converts the metal into tin dioxide, SnO_2, brown oxides of nitrogen being at the same time formed in abundance.

Several alloys of tin are in common use, the names and composition of the most important are given on p. 305.

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87. SILVER AND GOLD.

i. **Properties of silver.**—(*a*) Examine a piece of silver and notice as many of its properties as possible. Determine its relative density. Recall the uses of silver, and in this way remind yourself that silver does not tarnish, *i.e.* combine in ordinary circumstances with the oxygen of the air.

(*b*) If possible, examine a sheet of thin silver leaf between two sheets of glass. Observe that when very thin it transmits blue light.

(*c*) Place a silver spoon and an ordinary electro-plated spoon upon a sand-bath, as in Fig. 199. Upon the end of each put the end of a wax vesta without any wax with it, or hold the head of a match at the end of each when they are hot. Heat the sand-bath by placing a Bunsen burner under it. The match on the silver spoon will take fire before that on the other spoon.

ii. **Silver coins contain copper.**—Dissolve a threepenny piece in moderately strong nitric acid. Notice the blue colour of the solution. Refer to Experiment 82. iii. and satisfy yourself that silver coins contain copper, and that silver is soluble in nitric acid.

iii. **Action of light on silver compounds.**—To a solution of silver nitrate add a little dilute hydrochloric acid, and notice the white precipitate which is at once formed. Filter the solution and so obtain the white precipitate on a filter paper. Leave it exposed to light, and note its gradual change of colour.

iv. **Properties of gold.**—(*a*) Roll up a sheet of gold-leaf and drop it into strong nitric acid contained in a test-tube. The gold is not dissolved even when the acid is warmed.

(*b*) Add strong hydrochloric acid to the nitric acid in the last experiment, in this way making what is called *aqua regia.* The gold is now dissolved.

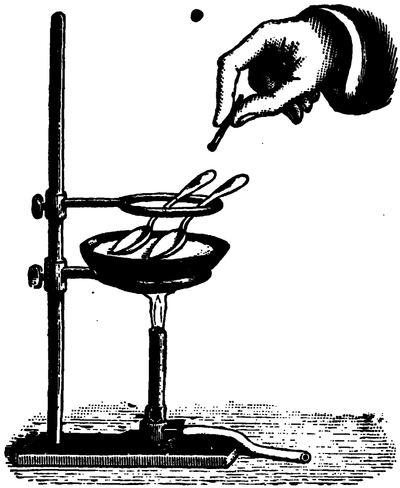

FIG. 199.—Simple method of showing that silver is a better conductor of heat than electro-plate.

Silver, Ag.—Silver is a white metal about ten and a half times as heavy as water. It does not tarnish when exposed to the air, even when heated. It is consequently much used for coinage and for ornamental purposes. It is, however, too soft to be used by itself, and is generally alloyed with copper. British coins contain about seven and a half per cent. of copper.

Silver conducts heat and the electric current more readily than any other metal. It is very malleable. When hammered into very thin leaves it is transparent to some constituents of white light, transmitting the light of wave-lengths correspond-

ing to the blue end of the spectrum. Silver is also very ductile and can be drawn out into wires of exceeding fineness.

Acids act upon silver, producing similar effects to those which have been studied under copper. Thus, hydrochloric acid has no action on silver; nitric acid dissolves it, forming silver nitrate, $AgNO_3$, and evolving oxides of nitrogen; and hot concentrated sulphuric acid dissolves silver, forming silver sulphate, Ag_2SO_4, and giving off sulphur dioxide.

Silver forms with sulphur a black sulphide of silver, Ag_2S. This explains the blackening of silver in ordinary rooms lighted by coal gas. The coal gas nearly always contains slight traces of sulphuretted hydrogen, SH_2, which act upon the silver with the formation of the black sulphide of the metal. Similarly, india-rubber contains sulphur, and if a silver coin is left in contact with a piece of india-rubber, the same blackening is noticed.

Several compounds of silver, notably the *chloride*, AgCl, the *bromide*, AgBr, and the *iodide*, AgI, are blackened by exposure to light, a fact which forms the basis of photography.

Gold, Au.—Gold is nearly always found native (p. 308) in nature, though it also occurs alloyed with other metals. Everybody is familiar with its bright yellow colour and with the circumstance that it is unacted upon by the air. It is more than nineteen times heavier than water. It is unacted upon by any of the common acids acting singly, though a hot mixture of strong hydrochloric acid and nitric acid will dissolve it. For this reason the mixture of these acids is known as *aqua regia.*

Gold is too soft in the pure state to be used either for coinage or for jewelry and is always alloyed with copper. This gives rise to the employment of the term *carat.* Pure gold is known as 24 carat gold. The British sovereign, which contains 22 parts of gold in 24 parts of the coin, is said to be made of 22 carat gold. Similarly, 9 carat gold consists of 9 parts of gold in every 24 parts of the article made of it.

It is the most malleable and most ductile metal known. Gold leaf has been made into sheets so thin that it would require more than a quarter of a million of them together to make a thickness of an inch. Gold wire of such an extreme thinness has been manufactured that two miles of it only possess a mass of one gram. Ordinary gold leaf, such as is used for gold lettering, is transparent to some constituents of the spectrum; it transmits green light quite readily.

CHIEF POINTS OF CHAPTER XXIII.

Metals.—Metals possess a peculiar lustre; they are opaque and very dense; they conduct heat and electricity well; they unite with hydrogen and oxygen to form bases.

Mixtures of metallic elements are called *alloys*.

Lead, Pb, has a bluish colour; its density is 11·5; it is malleable and ductile; it melts at 326° C. With oxygen lead forms *litharge* and *red-lead*; with sulphur it forms *galena*. It is one of the constituents of pewter, solder, and type-metal.

Iron, Fe, is the most important of metals. It is used in three forms, *wrought-iron*, *cast-iron*, *steel*. These forms have different properties. It is abundant in nature, *e.g.* combined with oxygen it forms *lodestone* and *haematite*; with sulphur, *iron pyrites*; with carbon dioxide, *clay ironstone*. Its density varies from 7·2 to 7·8.

Copper, Cu, has a red colour, it is hard, and does not change in dry air. Its density is about 9. It is very malleable and ductile. It is a very good conductor of the electric current. Common minerals in which it occurs are *ruby copper*, *copper pyrites*, and *malachite*. It is dissolved by moderately strong HNO_3 when cold, and is soluble in hot, strong sulphuric acid. Numerous alloys of copper are used.

Mercury, Hg, or *quicksilver* is the only liquid metal at ordinary temperatures. It is much used in thermometers and barometers. Its density is 13·5. It boils at 357·5° C. It dissolves many metals forming amalgams. Cold nitric acid and hot strong sulphuric acid dissolve the metal.

Sodium, Na, is lighter than water. Its density is 0·97. It has to be kept under naphtha because of its strong affinity for oxygen.

Zinc, Zn, is a blush-white metal. Its density is about 7. It does not easily combine with the oxygen of the air, and is extensively used to coat iron, as in *galvanised iron*. It is one of the constituents of brass. It occurs in nature combined with sulphur, and with carbonic acid. The metal easily dissolves in dilute hydrochloric, sulphuric, and nitric acids.

Tin, Sn, is a brittle white metal. Its density is 7·3. It is fairly malleable but not ductile. It does not combine with the oxygen of the air at ordinary temperatures, and is consequently used in the manufacture of *tinplate*. Many alloys of tin are in common use. It occurs in nature combined with oxygen as *tin-stone*, SnO_2. Tin is soluble in hot strong hydrochloric and sulphuric acids.

Silver, Ag, is a white metal. Its density is about 10·5. It does not tarnish in air, and when alloyed with copper is much used for coinage and jewelry. It is very malleable and ductile. The action of acids upon it is similar to the case of copper. Many compounds of silver are sensitive to the action of light, a fact which forms the basis of photography.

Gold, Au, is a bright yellow metal, which generally occurs native in nature. It is unacted upon by air, and is much used for jewelry and coinage. It is soluble in *aqua regia*. Pure gold is known as 24 *carat* gold. The British sovereign contains 22 parts of gold in 24 of the coin, and is called 22 carat gold. Gold is the most malleable and the most ductile of all metals.

EXERCISES ON CHAPTER XXIII.

1. What are the usual characters possessed by a metal? Name any exception you know to any of the properties you state.

2. What do you understand by each of the following terms: native gold, alloy, amalgam, carat?

3. Name three alloys in which copper occurs, and three in which lead is an important constituent.

4. What metals occur in each of the following minerals: cinnabar, haematite, galena, malachite, blende?

5. Enumerate the characteristic properties of lead, silver, and tin.

6. What metals do you know to be soluble in each of the following acids: hydrochloric, sulphuric, nitric?

7. What do you understand by galvanised iron and by tinplate? How are they made, and what reasons can you suggest for the processes?

8. To what uses are the following metals put: mercury, gold, and zinc? On what properties of the metals do these uses depend?

9. Write chemical equations for the action of sulphuric acid on sodium, zinc, and copper respectively

TABLE OF COMMON ELEMENTS, WITH THEIR SYMBOLS AND ATOMIC WEIGHTS.

Element.	Symbol.	At. Wt.	Element.	Symbol.	At. Wt.
Aluminium .	Al	27	Magnesium .	Mg	24
Antimony .	Sb	120	Manganese .	Mn	55
Argon . .	A	39·8(?)	Mercury . .	Hg	200
Arsenic . .	As	75	Nickel . .	Ni	58·7
Barium . .	Ba	137	Nitrogen. .	N	14·01
Bromine . .	Br	80	Oxygen . .	O	16
Cadmium .	Cd	112	Phosphorus.	P	31
Calcium . .	Ca	40	Platinum .	Pt	195
Carbon . .	C	12	Potassium .	K	39
Chlorine. .	Cl	35·5	Silicon . .	Si	28
Copper . .	Cu	63·6	Silver. . .	Ag	107·9
Gold . . .	Au	197	Sodium . .	Na	23
Hydrogen .	H	1	Sulphur . .	S	32
Iodine . .	I	127	Tin . . .	Sn	119
Iron . . .	Fe	56	Zinc . . .	Zn	65
Lead . . .	Pb	207			

PART III.: ASTRONOMY.

CHAPTER XXIV.

GUIDE TO THE CONSTELLATIONS AND CONSPICUOUS STARS.

Constellations.—One of the first impressions gained by an observer who looks at the sky on a starlight night is that the brighter stars form well-marked groups which constantly retain the same shape. A very conspicuous configuration or constellation of this kind can be seen when looking towards the north on any fine night. It is made up of seven stars, and, in general language, is known as the Plough, or Charles's Wain. Astronomers name the group Ursa Major, that is, the Great Bear. To the ancients, this and other conspicuous groups of stars bore a fancied resemblance to figures of men and animals, or some peculiarity was attributed to them which was also possessed by characters in heathen mythology. The Egyptians, Chaldeans, and Chinese were the first peoples who divided up the stars in this manner, but the earliest systematic grouping is contained in the *Almagest*, a great work written by a Greek astronomer named Ptolemy (140 A.D.). In that catalogue the stars are

divided into forty-eight groups, most of them being named after characters connected with the voyage of the ship *Argo*.

Designation of stars.—In spite of the unscientific plan adopted by ancient astronomers in mapping the heavens, the arbitrary division is, for convenience, still retained. The constellations may thus be considered analogous to countries on the earth, with the stars as towns. The majority of the bright stars possess proper names, such, for example, as Regulus, Aldebaran, and Rigel, but another method of designating them is by means of the letters of the Greek alphabet, giving the first letter (Alpha) to the brightest star in a constellation, the second (Beta) to the next brightest, and so on. Thus, Regulus is α Leonis, that is, Alpha of the Lion constellation; Aldebaran is α Tauri, that is, Alpha of the Bull, and Rigel is β Orionis—Beta of Orion.

Brightness of stars.—Everyone has noticed that there are various degrees of stellar glory, ranging from the brightest stars to those on the borders of invisibility. It is necessary in astronomy to adopt a scale of brilliancy, so that the brightness of a star can be expressed by reference to it. The system followed works upon the basis that on the average the light received from one of the brightest stars in the heavens is 100 times greater than that from a star which is only just visible to the naked eye. The difference of brightness between these two extremes could be divided into any number of steps, but for convenience the stars visible to the unaided eye are taken to be included in six degrees or orders of brilliancy; the brightest stars being classified as stars of the first magnitude, and the faintest naked-eye stars as stars of the sixth magnitude.

This system of classifying stars into magnitudes is not only applied to stars which are seen with the naked eye, but also to those which are revealed by the telescope.

Number of stars.—A glance at the sky on a fine night gives the idea that the stars are countless, but this is not so actually. If the whole of the heavens could be seen at any instant, less than 6000 stars would be visible to the naked eye, and as only one-half the celestial sphere can be viewed at one time, only about 3000 stars could be counted. An observer situated at the North Pole of the earth would see all the stars contained in the northern celestial hemisphere, and an observer at the South Pole would see all those in the southern celestial hemisphere.

The numbers of stars of each magnitude observable in England are approximately as follows:

First magnitude	about	14	stars
Second	,,	48	,,
Third	,,	152	,,
Fourth	,,	313	,,
Fifth	,,	854	,,
Sixth	,,	2010	,,
Total,		3391	stars

It will be noticed that the stars become more numerous as the magnitude becomes fainter.

Stars fainter than the sixth magnitude can only be seen with optical aid. Even a small telescope is sufficient to add very considerably to the visible universe. With a telescope less than 3 inches in diameter it is possible to see about 300,000 stars in the northern celestial hemisphere, and with the largest telescopes now in use something like 100,000,000 stars are brought within the ken of the observer.

The northern sky.—Seven bright stars forming a large group can always be seen when facing the north on a fine night in England. They are often called "Charles's Wain," "The Plough," or "The Dipper." The two stars most distant from the curved tail serve to indicate the position of a star which should be familiar to everyone. They are known as "The Pointers," because a line connecting them points very nearly to the Pole Star or North Star (Fig. 200). Not far from the Pole Star can be seen two other fairly bright stars, known as the "Guards of the Pole," and belonging to the Little Bear.

After the Great Bear, the next most conspicuous group in the northern sky belongs to the constellation of Cassiopeia. The chief stars form a broadened **W**, known as the Cassiopeia's Chair, the top of the **W** being directed towards the Pole. A line from the middle star in the tail of the Great Bear, if carried through the Pole Star and continued for the same distance on the other side, leads to Cassiopeia.

Between the Great Bear and the "Guards," and extending round to Cassiopeia, are the constellations Draco (the Dragon) and Cepheus, neither of which is distinguished by very distinct configurations of stars.

The Great and Little Bears, Cassiopeia, and other groups of stars in their neighbourhood, are always visible on a fine night in England. Sometimes they are high above the northern horizon, sometimes low down, but never invisible unless

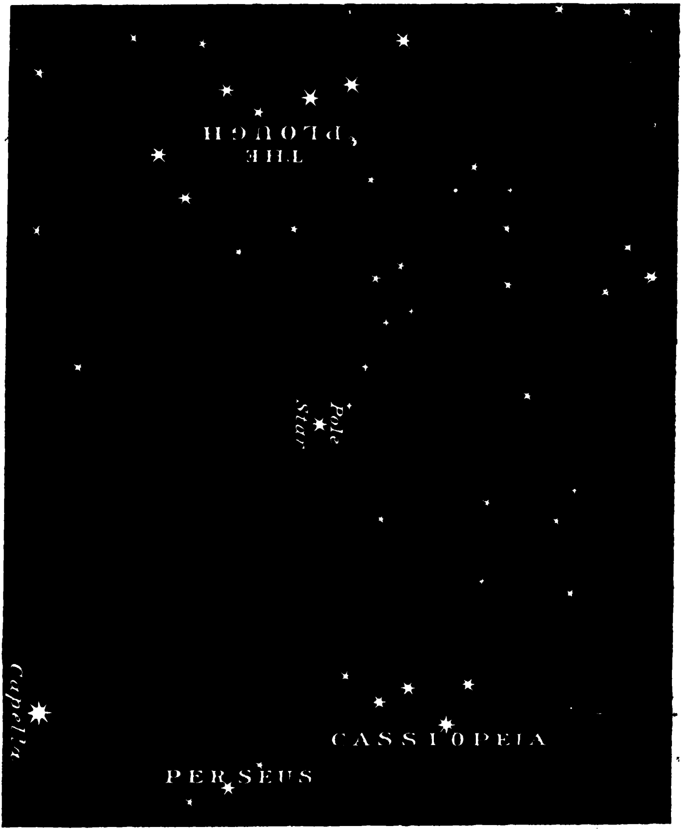

FIG 200.—Stars always visible when facing north on a fine night in England.

obscured by clouds. In addition to these *circumpolar* constellations, there are others which are only seen at certain seasons of the year. These are represented upon the accom-

panying maps (Figs. 201-4), and will now be briefly surveyed. The stars in each constellation are connected by a faint dotted line.

Winter constellations.—In the winter months three brilliant stars in a line can be seen when looking south (Fig. 201). The configuration is so conspicuous that a glance upward is all that is required to recognise it. These stars form the

Fig. 201.—Constellations visible when looking south in autumn and winter. The left side is east and right side west.

Belt of Orion (pronounced O-rī-on), and belong to a splendid constellation, which has only to be seen to be remembered. Four bright stars, in the form of an oblong, surround the belt and mark different parts of the body of the giant Orion.

Orion's Belt is a useful guide to the positions of other stars. Continue its direction upwards to about five times its length, and a bright star of a ruddy colour is met. This is Aldebaran (pronounced Al-dé-baran), the brightest star in the constellation of the Bull (Taurus). Carry the line still further, and a beautiful cluster of stars known as the Pleiades (pronounced Plī-ā-dēz) is seen. Six stars can easily be distinguished with the naked eye, and as many as ten have been counted in the cluster by persons gifted with keen vision. A small telescope reveals about a hundred stars, and nearly three thousand have been counted upon a photograph of the group.

By again using Orion's Belt as a guide, the constellation of the Great Dog (Canis Major) can be found. The line of stars points downward to the brightest gem in the sky, known as the Dog Star, or Sirius. To the north-east of Sirius, another bright star, Procyon (pronounced Pro-si-on), will be found. Betelgeuse (pronounced Bé-tel-gus), Sirius, and Procyon, form a triangle, having sides of equal length (Fig. 202).

The constellation Gemini (the Twins) next claims attention; it lies to the north-east of Orion. A line from Procyon carried towards the tail of the Great Bear passes near the two chief stars, Castor and Pollux, in the constellation. Pollux is about the same distance north of Procyon that Procyon is east of Betelgeuse, whilst Castor lies slightly to the north-west of his brother.

Spring constellations.—Leo, the Lion, is the chief constellation visible when looking south about ten o'clock in the Spring. In outline it bears a resemblance to an Egyptian sphinx. The Pointers produced backwards lead to this figure. Regulus (pronounced Rég-u-lus), the brightest star in the constellation, lies near the place where the directing line cuts the body of the Lion. Above it occurs a line of stars, curved like the blade of a sickle. Indeed, these stars form a very good sickle, with Regulus at the end of the handle. A line from Procyon, through Regulus, passes over Denebola (pronounced Dé-né-bo-la), a fairly bright star in the Lion's tail.

The constellation Virgo, the Virgin, lies south and east of the Lion (Fig. 203). A line drawn in a south-east direction from Denebola reaches Spica (Spī-ka), the principal star in Virgo.

Summer constellations.—The end of May sees the constellation Bootes (pronounced Bo-ötes) due south at ten o'clock. Its

principal star, Arcturus (pronounced Ark-tū-rus), is almost as brilliant as Sirius, but of a different colour. By continuing the curve of the handle of the Plough, the star is at once found. Another guide is formed by drawing a line from Regulus

FIG. 202.—Constellations visible when looking south in winter and spring. The left side is east and right side west.

through Denebola, and producing it until the reddish-coloured star is reached. A large equilateral triangle can be recognised in the heavens, with its corners marked by Spica, Denebola, and Arcturus, the last-named star being situated at the northern apex of the figure.

North-east of Boötes occurs a constellation which has been named the Corona Borealis, or Northern Crown. The stars in this group are arranged in the form of a semicircle, and are thus

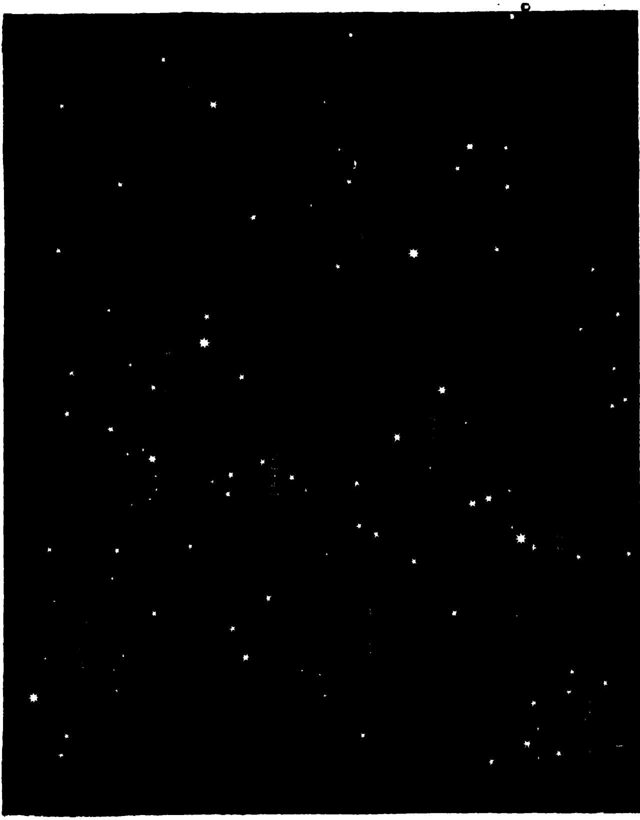

Fig. 208.—Constellations visible when looking south in spring and summer. The left side is east and right side west.

rendered easy of recognition. To the north-east again occurs the constellation Hercules.

Autumn constellations.—Some fine constellations can be seen when looking towards the south at ten o'clock in the months of August and September. High up in the south a brilliant, bluish-coloured star, called Vega (pronounced Vee-ga) attracts

the attention of the most casual observer. It forms a triangle with the Pole Star and Arcturus. Two fairly bright stars will be seen forming a small obtuse triangle with Vega, and the three represent the chief objects in the constellation Lyra.

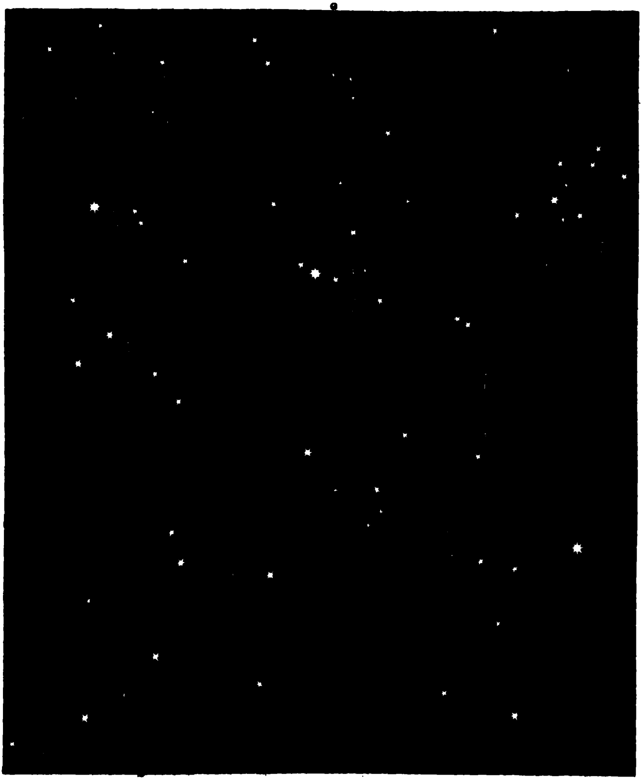

FIG. 204.—Constellations visible when looking south in summer and autumn. The left side is east and right side west.

Cygnus, the Swan, has the form of a cross, and lies close to Lyra. The brightest star in this constellation marks the top of the cross, and makes a right-angled triangle with the Pole Star and Vega, itself situated in the right angle.

The bright star Altair, in the constellation Aquila, can be seen when looking south about ten o'clock in the beginning of

September. A line from the Pole Star, through the cross of Cygnus, if continued for about the same distance towards the south, leads to Altair—the middle of three stars in a line—all of which belong to the constellation of the Eagle.

An extremely well-marked group, covering an enormous area of sky, arrests the attention in October. Four stars in the form of a square, known as the Great Square of Pegasus (Peg-a-sus) (Fig. 204) are visible when looking towards the south about ten o'clock. The group is so conspicuous that a directing line is hardly required to point it out. Should there be any difficulty, however, carry a line from the Pole Star past the brightest side of the **W** in Cassiopeia, and the square will be found. By connecting the two stars which form the western edge of the square, and producing the line southwards for about three times the distance, Fomalhaut (Fō-ma-lo), a solitary bright star in the constellation of the Southern Fish, is located.

The four stars which make up the Great Square of Pegasus do not all belong to this constellation. That in the north-east corner and nearest Cassiopeia is really Alpha Andromeda. A line from the Pole Star through the side of the **W** in Cassiopeia most distant from the Pole indicates the position of this star. It is noteworthy that the stars on this line appear due south at the same time. The line connecting them happens to lie very close to what may be termed the "Greenwich meridian" of the sky, for it is used in much the same way as the meridian which passes through Greenwich Observatory, being the zero line from which astronomers reckon celestial "Right Ascension," which is the celestial equivalent of longitude on the earth.

From *Alpha* Andromedae, and extending to the north-east under Cassiopeia, a curved line of stars can be made out. The first three stars belong to Andromeda, but that with which the line is terminated is the chief star in the constellation Perseus.

Perseus and Andromeda are best seen about the end of November. The brightest star in the former constellation is situated between two fainter stars, one to the north-west, the other to the south-east of it. A remarkable object in this constellation is the variable star Algol. It is in the right angle of a right-angled triangle which it forms with *Alpha* Persei and *Gamma* Andromedae. In an interval of a little less than three

days Algol periodically blazes out and then fades into comparative insignificance.

A line from *Gamma* Andromedae, if imagined to pass midway between Algol and *Alpha* Persei, points out Capella (Ka-pél-a) in the constellation Auriga (Aw-ri-ga). Capella and Algol are at the top of a V-shaped configuration, having Aldebaran in the angle.

CHIEF POINTS OF CHAPTER XXIV.

Constellations are groups into which astronomers have arranged the stars according to their positions on the sky. Ptolemy (140 A.D.) named forty-eight groups, and about twenty names since added are accepted. Constellations are analogous to countries, names of bright stars are analogous to names of cities; and a star catalogue is analogous to the index at the end of an atlas.

Stars are arranged in magnitudes according to their brilliancy, the first magnitude including the brightest stars, and the sixth the stars just visible to the naked eye. It is agreed that a star of any magnitude is two and a half times brighter than one a magnitude fainter.

Number of stars.—On the best night about 2500 can be seen with the naked eye at one time. A three-inch telescope will show 300,000 in the same celestial hemisphere, and the largest telescope about 100,000,000 in the whole sky.

Circumpolar constellations are visible on every fine night. The chief circumpolar constellations visible from England are Ursa Major (Great Bear), Ursa Minor (Little Bear), Cassiopeia, Cepheus, Draco (The Dragon), Perseus (partly), Andromeda (partly).

Constellations visible in England when facing south.—In the middle of each month, about 10 p.m., the following are the chief conspicuous constellations seen when facing south. The same constellations are south about midnight in the preceding month, and 8 p.m. in the following month:

Month.	Constellations.
January . . .	Gemini, Orion, Auriga, Canis Major.
February . . .	Cancer, Canis Minor.
March . . .	Leo, Hydra.
April . . .	Virgo, Canes Venatici.
May . . .	Libra, Boötes.
June . . .	Scorpio, Corona, Hercules, Ophiuchus.
July . . .	Sagittarius, Lyra.
August . . .	Capricornus, Aquila, Cygnus.
September . .	Aquarius, Pegasus, Piscis Australis.
October . . .	Pisces, Cetus.
November . .	Aries, Perseus, Cetus.
December . .	Taurus, Auriga, Eridanus.

Brightest stars visible in England.—The following are the names of the brightest stars visible in England, arranged in order of brightness, and the constellations in which they occur:

Name of Star.	Latin Name of Constellation.	English Name of Constellation.
Sirius	Canis Majoris	Great Dog.
Arcturus	Boötes	Boötes.
Capella	Auriga	Waggoner.
Vega	Lyra	Lyre.
Rigel	Orion	Orion.
Procyon	Canis Minoris	Little Dog.
Betelgeuse	Orion	Orion.
Achernar	Eridanus	The River.
Altair	Aquila	Eagle.
Aldebaran	Taurus	Bull.
Antares	Scorpio	Scorpion.
Spica	Virgo	Virgin.
Fomalhaut	Piscis Australis	Southern Fish.
Pollux	Gemini	Twins.
Regulus	Leo	Lion.
Alpha Cygni	Cygnus	The Swan.
Castor	Gemini	The Twins.

EXERCISES ON CHAPTER XXIV.

1. Give the names of the six brightest stars visible from a place in England, and state the season of the year in which the stars could be seen.
2. What is meant by the "magnitude" of a star? What "magnitude" would you estimate the Pole Star to be?
3. Make a sketch showing the relative positions of the constellations of the Great Bear, Little Bear, and Cassiopeia at the present time of year.
4. At what seasons of the year are the following stars visible: Vega, Rigel, Regulus, Pole Star, Arcturus, Capella?
5. What conspicuous constellations are visible when looking south about 10 p.m. in September and January?
6. Make a sketch showing the relative positions of the chief stars in the constellation of Orion.
7. Show upon a sketch the relative positions of the conspicuous stars in the constellations Lyra, Cygnus, and Aquila.
8. Give the names of six constellations, and state the best season of the year to observe the stars in these groups.
9. How would you teach a child on a clear night the way to find the North Polar Star?

CHAPTER XXV.

THE CELESTIAL SPHERE AND ITS DIURNAL MOTIONS.

88. ANGULAR MEASUREMENTS UPON THE CELESTIAL SPHERE.

i. **Angular measurement applied to the sky.**—(*a*) Obtain two thin rods of wood about a foot in length. Place the two together and push a pin through them both near one end, so as to hold them like the legs of a pair of compasses. Using a rough arrangement of this kind, or a better instrument if one is available, measure some angular distances upon the celestial sphere. For instance, point one of the legs to the Pole Star and the other to the nearest of the Pointers; then place the legs so that their junction lies at the centre of a circle divided into degrees (Fig. 17), and determine the angle between them.

(*b*) In the same way measure other angular distances, such as between the following stars: (1) The two stars of the Pointers; (2) the Pointer nearest the Pole Star, and the last star in the handle of the Plough; (3) the Pointer nearest the Pole Star, and the fainter star at the bend of the Plough handle; (4) the shortest distance between the W group in Cassiopeia and the Pole Star; (5) the distance of Capella from the Pole Star.

ii. **Angular distances between conspicuous stars.**—Verify as many of the following angular distances between stars as the season of the year will permit:

Betelgeuse—Rigel,	19°
Middle star in Orion's Belt—Sirius,	23°
Sirius—Procyon,	25°
Rigel—Castor,	53°
Altair—Vega,	34°
Altair—Fomalhaut,	60°
Aldebaran—Pleiades,	14°
Procyon—Pollux,	23°

iii. **A simple altitude and azimuth model.**—Cut out a semi-circular piece of cardboard and divide it into 180 equal parts or degrees. Also cut out a circular piece of cardboard a little greater in diameter and divide it into degrees. Fix this circle flat upon a piece of wood. Obtain a thin, narrow strip of wood about equal in length to the diameter of the circle, and push a drawing-pin through the centre. Fix the cardboard semi-circle vertically upon the strip of wood, and

by means of a drawing-pin fasten one end of a strip of cardboard or a thin rod of wood so as to form a pointer or hand capable of being moved in a vertical plane. Now place the semi-circle as in Fig. 205. with the drawing-pin at the centre to form a vertical axis about

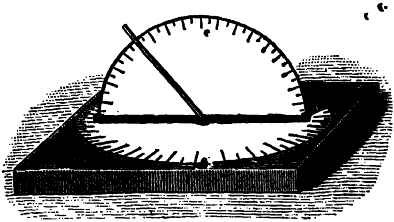

FIG. 205.—Model to illustrate altitude and azimuth.

which it can turn. This simple arrangement may be used to illustrate the meaning of "altitude" and "azimuth," and to show that two co-ordinates like these determine the position of an object at any particular moment.

iv. **An instrument for measuring altitude and azimuth.**—It is difficult to take a sight along a rod arranged upon a semi-circle in the manner described, but very little ingenuity is required to construct an apparatus by means of which altitudes and azimuths can be roughly measured. For instance, a simple instrument can be made as follows: Obtain a shallow wooden box about a foot square, and a rod of wood about an inch in diameter and a foot in length. At the centre of the cover of the box bore a hole slightly greater in diameter than the rod of wood. Through the bottom of the box hammer a wire nail, so that it stands vertically pointing to the centre of the hole made in the cover. Bore a hole at the centre of one end of the rod, so that the rod will fit upon the nail. The rod can thus turn on the nail as a vertical axis when it is pushed through the hole in the top of the box. (Fig. 206.)

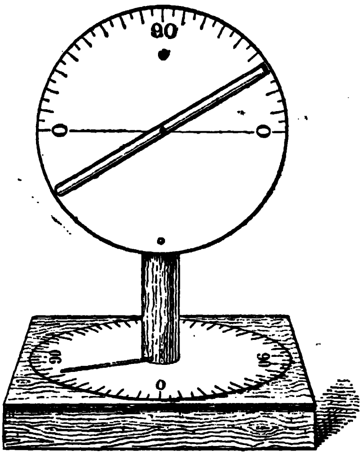

FIG. 206.—Simple model for the measurement of altitude and azimuth.

Cut a hole, slightly greater than the diameter of the rod, in the centre of a cardboard circle divided into degrees. Fasten the circle upon the top of the box. Push a knitting-needle into the rod, so that it lies upon the horizontal circle in the direction of a radius of the circle. The needle will serve as a pointer to indicate the azimuth upon the horizontal circle. Divide half of a second circle into degrees, and fix it upon the rod vertically, with the diameter connecting the end divisions in a horizontal position, and the divided semi-circle above it. Obtain a narrow tube of cardboard or a thin rod of wood. Push a wire nail across the middle and into the rod at the centre of the vertical circle. The altitude of an object will be shown by means of the vertical circle, the divisions of which should be numbered from 0 to 90 in each of the upper quadrants, the division 90 being at the top.

v. **Determinations of altitude and azimuth.**—Arrange the altitude-azimuth instrument so that the 0 of the horizontal circle is due south and the knitting-needle points to 0. Turn the rod until some distinct object on the wall or ceiling of the room can be sighted through the tube or along the thin rod on the vertical circle. Notice the number of degrees the knitting-needle pointer has moved from the 0 or south point. (This shows the azimuth of the object observed.) Notice also the number of degrees between the horizontal diameter of the vertical circle and the direction of the sighting tube or rod. (This shows the altitude of the object.) Determine the positions of several objects in the same way, writing down the altitude and azimuth of each thus:

Object.	Azimuth.	Altitude.
Spot on wall . .	53°	67°
Window fastener . .	130°	74°
Ventilator . . .	99°	83°

Now reverse the operations by arranging the apparatus so that the sighting-tube or rod has the altitude and azimuth previously measured for one of the objects. It will thus be found that the position of a fixed object can be determined when the altitude and azimuth are known. It is a good exercise to write down the altitudes and azimuths of several objects and let some one else determine the objects by setting the sighting-tube or rod in the position indicated by the numbers and looking along it.

The celestial sphere.—Though all the stars are really moving through space, they are so far removed from the earth that their real motions can only be detected after several years even with very refined astronomical instruments. So far as ordinary observations are concerned, the stars may be regarded as fixed points upon a celestial sphere. The sphere has, of course, only an imaginary existence—it is merely a name, or a convenient

geometrical background—and the stars, or any object in the universe, can be considered to be projected upon it. This should be borne in mind in considering what follows, both as regards text and illustrations. When a clear idea is obtained of the significance of the celestial sphere, it is easy to understand how the position of celestial bodies can be measured in angles upon it.

Horizon.—Consider a plumb-line to be suspended at any place; its direction is vertical and varies according to its position on the earth. A plane perpendicular to this plumb-line, if produced to meet the celestial sphere, marks out a great circle known as the *sensible horizon* of the place of observation. If an observer be imagined, then the plane may be regarded as passing through his eyes perpendicular to the direction of a plumb-line where he stands. For astronomical purposes, it is best to imagine a plane parallel to this one, but passing through the earth's centre instead of the surface at the place of observation. The great circle formed upon the celestial sphere by this plane passing through the earth's centre, and perpendicular to the direction of a plumb-line at the place of observation, is known as the *rational horizon*. As the earth is only a point in relation to the celestial sphere, the sensible and rational horizons become, for all practical purposes, one celestial horizon (Fig. 207).

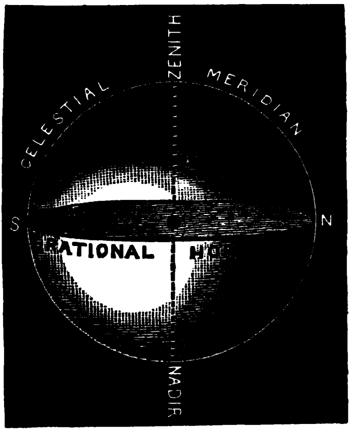

Fig. 207.—The celestial sphere in relation to an observer's horizon.

In ordinary language the word horizon signifies the line where earth and sky appear to meet, and it usually has an irregular outline. This is known as the *visible horizon*, and it is never more than a few miles distant from the observer, thus differing from the sensible and rational horizons, which are imaginary circles upon the celestial sphere. Suppose a plane to lie on the surface of a liquid at a place; such a

plane is a horizontal plane, and where it cuts the celestial sphere the sensible horizon is marked out. At a distance of a mile from the point of observation, the visible horizon would, owing to the earth's curvature, be eight inches below this plane.

The surface of a liquid at rest is perpendicular to the direction of a plumb-line at every place on the earth. The plumb-line is vertical, and it points upwards to the *zenith* and downwards to the *nadir*. The zenith and nadir are thus opposite points upon the celestial sphere, and their positions depend upon the position of the observer. The horizon is equidistant from these two points in much the same way that the equator of the earth is midway between the two poles.

The semicircular line which can be imagined to be drawn through the zenith of a place from the north and south points of the horizon is termed the *celestial meridian* of that place.

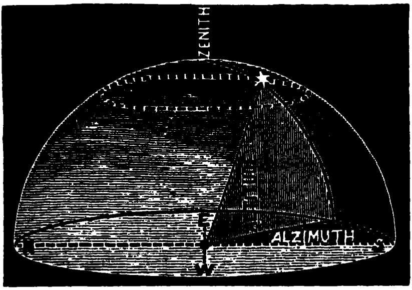

FIG. 208.—Altitude and azimuth system of co-ordinates.

Altitude and azimuth.—To locate the position of an object by two measurements—known as co-ordinates—it is necessary to have two lines or planes at right angles to one another from which to measure. In the case of celestial objects, the sensible horizon is the plane from which the angular height or altitude, is measured.

The line from which the azimuth is measured is the line which joins the north and south points of the horizon.

Thus, then, when we have measured the altitude of a star, we know that it is at a certain distance above the horizon, and when, in addition to this, we know its azimuth, we are aware that it is at a certain distance from the north and south line above mentioned. From this it will be understood that the

position of a celestial object at any instant may be defined by the altitude and azimuth system of co-ordinates. It should be borne in mind, however, that when bodies are moving there is a continual change of altitude and azimuth.

Declination and Right Ascension.—The azimuth and altitude of a celestial body are continually changing, and are therefore not convenient co-ordinates for defining the absolute position of an object upon the celestial sphere. Two other co-ordinates, viz., Right Ascension and Declination, are used instead of

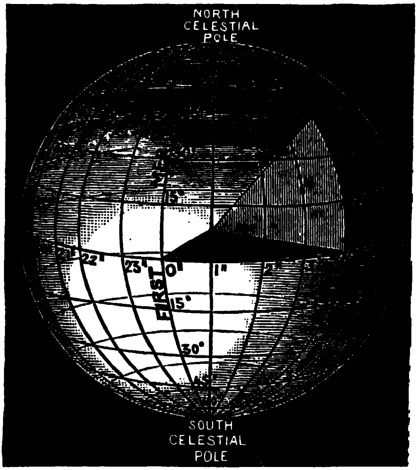

FIG. 209.—The celestial sphere, showing the celestial poles and equator, and explaining Right Ascension and Declination.

azimuth and altitude. Right Ascension is analogous to longitude on the earth, and Declination to latitude. The celestial poles may be regarded either as the points in the celestial sphere directly above the poles of the earth, or as the points where the earth's axis produced meets the celestial sphere. The celestial equator is a line drawn round the sphere half-way between the poles. Circles passing through both poles thus cut the celestial equator at right angles.

The celestial co-ordinate termed *Declination* may be defined as angular distance north or south of the celestial equator, and is measured in degrees, minutes, and seconds of arc.

The ecliptic, along which Right Ascensions are measured, is the apparent path in which the sun travels around the celestial sphere in a year. (See Chap. XXVII.) On March 21 in each year the sun is directly in front of the point of intersection, known as "the first point of Aries," of the celestial equator with the ecliptic. This is the point from which *Right Ascensions* are reckoned, just as terrestrial longitudes are measured from Greenwich. Right ascensions are generally reckoned from 0 hours to 24 hours of sidereal time from west to east, that is to say, in the opposite direction to the apparent diurnal movement of the heavens.

89. APPARENT DIURNAL MOTIONS OF STARS.

i. Diurnal paths of circumpolar stars.—(*a*) Face the north on any fine night and direct one leg of a pair of compasses, or of two hinged rods, to the Pole Star. Point the other leg to a star in the Plough or Cassiopeia. Keeping the leg directed towards the Pole, describe a circle with the other. This circle indicates the apparent diurnal path followed by the star under observation.

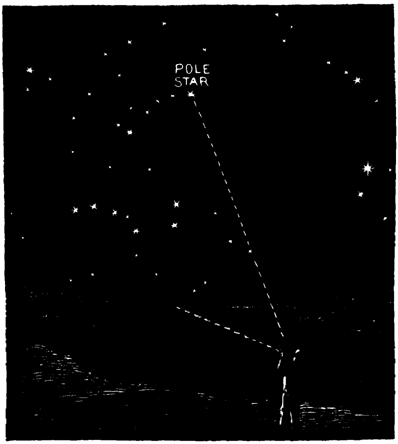

FIG. 210.—The altitude of the pole is equal to the latitude of the place.

(*b*) Open the compass or hinged rods until one leg points to the Pole Star and the other to the horizon, with the plane of the legs vertical. A circle described with this radius embraces all the stars visible, to an observer on a clear night, from the place of observation. Such stars are "circumpolar" stars. Measure the angle between the

legs by means of a protractor or divided circle; or better, measure the altitude of the Pole Star with the instrument described on p. 330 (Fig. 206).

ii. **Photography of diurnal circles of stars.**—Arrange a camera to point towards the Pole Star. Insert a sensitive plate in the dark slide, and expose it for as many hours as you can to the sky on a fine night, when there is no moon. Afterwards take out the plate and develop it. Notice that the "trails" of the stars are arcs of circles which have a common centre.

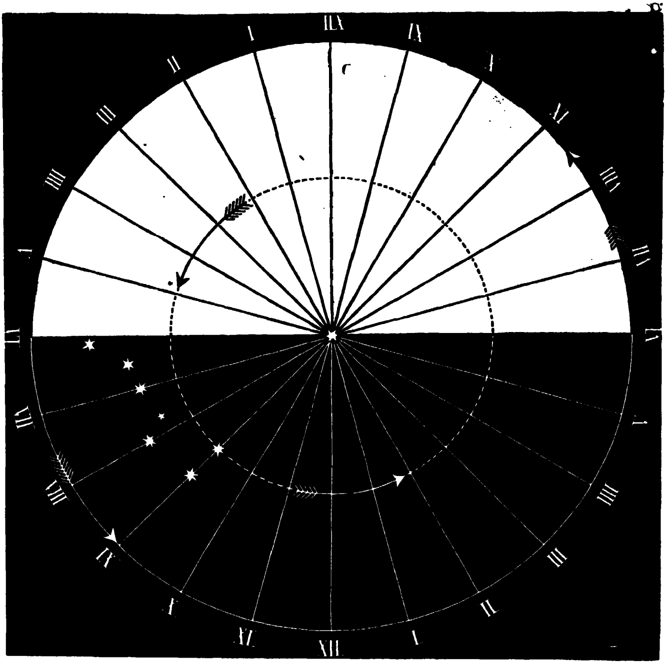

FIG. 211.—To illustrate how the position of the Plough group of stars changes from hour to hour on account of the apparent diurnal movement of the celestial sphere. The Roman numerals show the positions at different hours in September.

Apparent diurnal movement of circumpolar stars.—Though the configurations of stars observed in the sky remain practically the same from year to year, the whole of the stars appear to be carried round the heavens once in about twenty-four hours. So far as appearances go, the stars may be con-

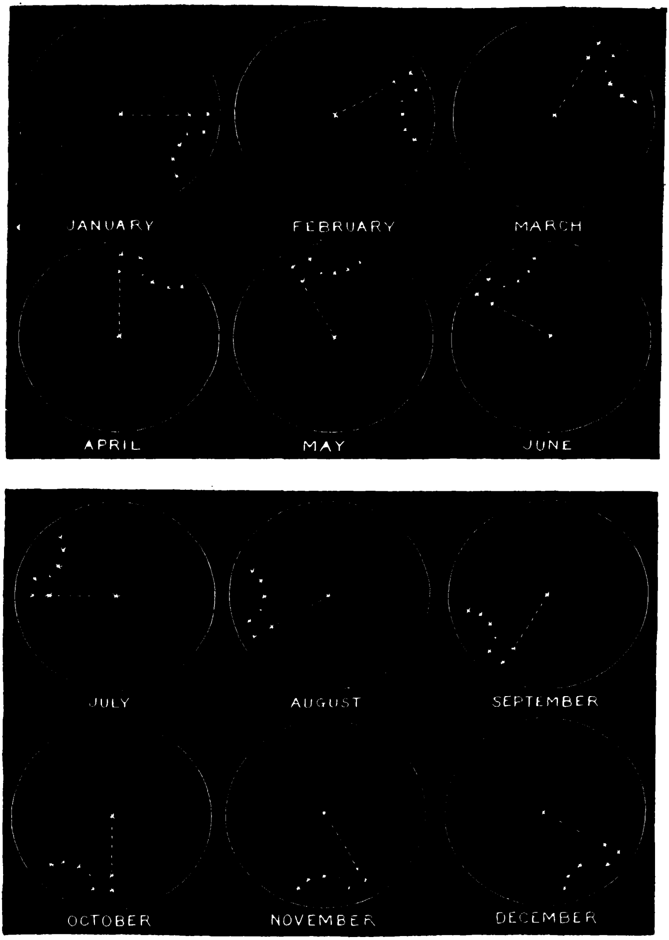

Fig. 212.—Position of the Plough group in relation to the north celestial pole about 9 p.m. in each month.

sidered as electric lamps fixed in a vast dome which turns once a day upon an axis passing through a point near the Pole Star,

the direction of motion to an observer looking towards the north being opposite to that in which the hands of a clock move. If the sun did not obliterate the light of the stars, we should be able to trace this apparent diurnal movement completely round the Pole. As it is, the observation of the movement is limited to the hours of night.

These apparent diurnal movements can be used as a celestial time-keeper. The position of the Plough group at 9 p.m. in September is shown in Fig. 211. Imagine a line to pass through

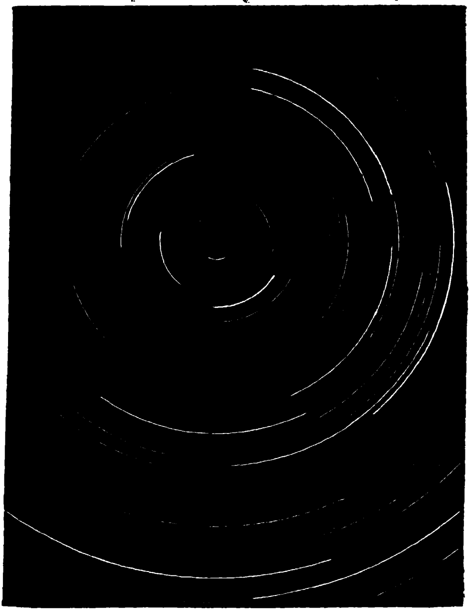

FIG. 213.—Photographic record of the apparent diurnal motions of stars within a few degrees of the north celestial pole. Exposure, 4 hours 10 mins.

the Pointers and the Pole. This line may be regarded as the hour-hand of a celestial clock, and the position it occupies at each hour at the time of year selected is shown upon the illustration. The diagram there given is for September, but a similar dial can be constructed for any month. Whether the Pointers are obscured upon any night in the year or not, the

position of the line through them and the Pole changes at the rate of about $\frac{1}{24}$th of a circle per hour, that is 15° per hour, in precisely the same way as is represented in Fig. 211. The position of the Plough at 9 p.m. in the middle of each month is shown in Fig. 212.

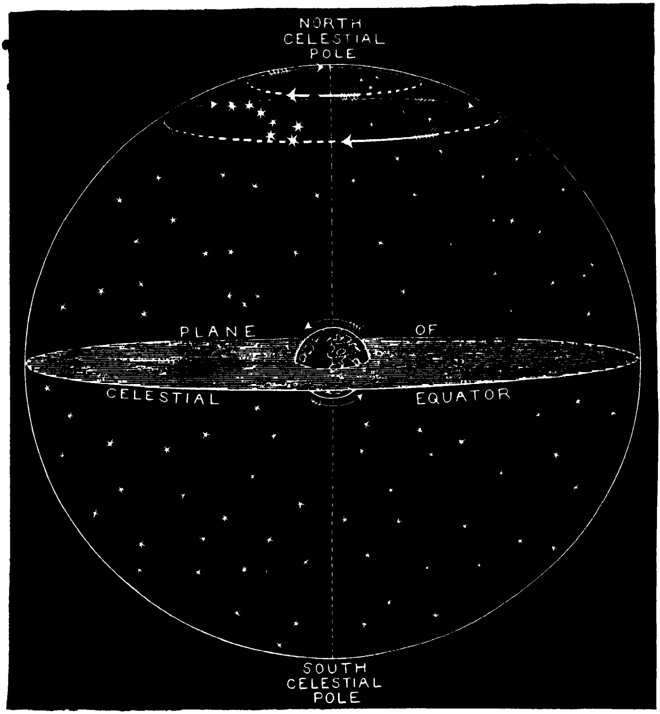

FIG. 214.—The apparent diurnal movement of the celestial sphere, produced by the real rotation of the earth on its axis.

A striking demonstration of the apparent diurnal rotation of the heavens is obtained by means of photography. The photographic plate is able to record the apparent movements of the star towards which its sensitive face is turned. During the time that a camera containing such a plate is directed towards

the sky, the stars are apparently carried round the Pole in the way already described, the result being that they all leave trails upon the photographic plate (Fig. 213). The trail of the Pole Star is the arc of a circle at a distance of about one-third of an inch below and to the right of the North Celestial Pole, which is the centre of all the arcs. A similar result is obtained if a photograph is taken of the region around the South Celestial Pole by a photographer in the southern hemisphere.

The earth in space.—The *apparent* diurnal rotation of the celestial sphere can be satisfactorily explained by considering it as an effect produced by the *real* rotation of the earth. The North and South Poles of the heavens are the points at which the earth's axis of rotation produced would touch the celestial sphere (Fig. 214). In a similar way, the celestial equator is the line of intersection of the earth's equator with the celestial sphere.

To prevent misapprehension it may be worth while to point out that the earth is not actually in the centre of the universe of stars, as might be suggested by the accompanying diagram (Fig. 214). The stars are irregularly distributed throughout space, and are seen in all directions from the earth, but as space is infinite in extent, any object can be considered as the centre of the celestial sphere. It does not, therefore, signify whether the earth or any star is taken as the centre of the universe, for whichever is selected there is no end from it in any direction. Hence, though there is no reason at all for considering the earth as in the middle of the system of stars, it may be regarded as the centre of an imaginary celestial sphere having an infinite radius. The positions of the poles and equator of this sphere are, as has been explained, determined by the direction of the axis of rotation of the earth. If the earth could be turned upside down, what is now the southern celestial hemisphere would become the northern, and the Plough and other northern constellations would be southern stars.

Relation between the altitude of the Pole and latitude.—The North Pole of the heavens is on the horizon of an observer situated at the equator. It appears higher and higher in the sky as a journey is made northwards from middle latitudes, and, at the North Pole, it is exactly overhead. There is, in fact, a close connection between latitude and the angular distance of the celestial pole from the horizon. The latitude, or angular

distance from the equator, of any spot on the earth is equal to the altitude of the celestial pole at that place. Hence, a rough determination of the latitude of a place can be made by noticing the altitude of the Pole Star above the horizon.

Altitude of equator.—From the north point of the horizon to the zenith is an angle of 90°; and from the zenith to the south point is also 90°; the whole angle from the north to the south point through the zenith is thus 180°. Knowing the elevation of the celestial pole above the north point, and knowing also that the Pole is 90° from the equator, the elevation of the celestial equator above the south point of the horizon can be found. Consider a place in latitude 50° N. Then

From N to S through zenith	=180°
From N to N celestial pole	= 50°
From N celestial pole to equator	= 90°
Therefore, from equator to S point	=180° − (50° + 90)
	= 40°

Or, expressed in another way, the altitude of the celestial equator above the south point of the horizon of the place of observation is equal to the difference between 90° and the latitude of the observer (Fig. 215).

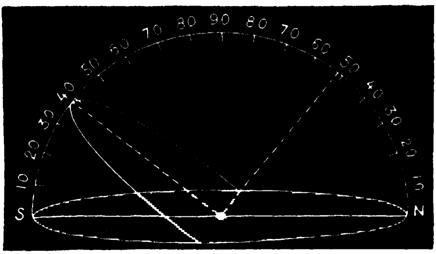

Fig. 215.—Inclination of the celestial equator to the horizon of London.

The position of the celestial equator is, of course, constant for any one latitude, in the same way as the altitude of the celestial pole is constant for one particular place. No definite line of stars marks the position of the equator, but its general direction can be determined by remembering the rule already stated as to its altitude, and that it always passes through the east and west points of the horizon.

Spheres of observation.—Regarding the stars as fixed points on a celestial sphere, and the earth as a globe rotating within the sphere, it is easy to understand and explain all the appearances presented by the heavens. The following points should be borne in mind:

(1) Only one half of the celestial sphere can be seen by a single observer at any instant.

(2) The celestial hemisphere visible has for its zenith the point directly above the head of the observer, and the horizon passes through the centre of the earth 90° from the zenith.

(3) On account of the earth's rotation, each star appears to describe a diurnal circle around a celestial pole, and the radius of the circle depends upon the distance of the star from the pole.

(4) The centre of the diurnal circle has an altitude equal to the latitude of the place of observation.

Diurnal circles of circumpolar stars.—It has been seen that all stars, the angular distance of which from the Pole is not greater than the latitude of the place of observation are always visible on a fine night, that is, they are circumpolar. Hence, to determine the apparent circle described by any star at any place, all that it is necessary to know is the latitude of the place and the angular distance of the star from a celestial pole (or its distance from the celestial equator, for, as in the case of terrestrial latitude, angular distance from Pole = 90° minus angle from equator). A few examples will show how to apply this principle.

Example 1.—The last star in the handle of the Plough is 50° from the celestial equator. About what latitude is it just not a circumpolar star?

As the star is 50° from the Equator, it is 40° from the Pole; so that its diurnal circle is 40° from the Pole. The horizon of a place in latitude 40° N. touches the bottom of this circle, therefore the complete diurnal course of the star will be observable in latitude 40° N. In lower latitudes, however, say 30° N., the Pole is only 30° or less above the horizon; hence the complete course of a star 40° from the Pole cannot be observed.

Example 2.—The brightest star in the constellation of Cassiopeia is about 34° from the Pole. What are the greatest and least altitudes which the star attains in latitude 55° N.?

Altitude of Pole	=	Latitude	=	55° N.
Distance of star's diurnal circle from Pole			=	34°.
Least altitude	=	55° − 34°	=	21°.
Greatest ,,	=	55° + 34°	=	89°.

Example 3.—The bright star Capella is about 44° from the North Celestial Pole. In what latitude does it become a circumpolar star?

Distance of Capella's diurnal circle from Pole as centre = 44°.

And as Altitude of Pole = Latitude.

Therefore in any north latitude greater than 44° the complete diurnal circle of Capella will be observable.

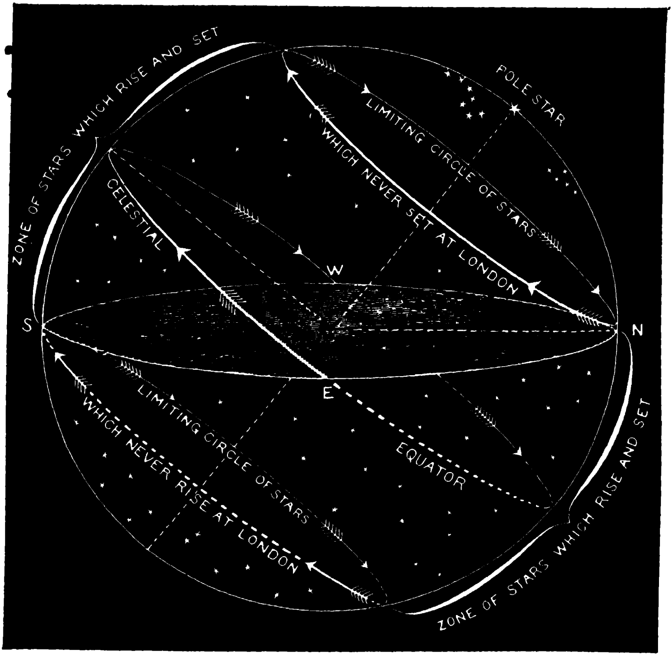

FIG. 216.—Position of the horizon of London in relation to the celestial sphere and the diurnal circles of stars.

Apparent movements of stars not circumpolar.—So far only the diurnal motions of circumpolar stars have been described, but the observations may now be extended. Again using a pair of compasses, or two hinged rods for measurement of angles, let one leg be directed towards the North Pole of the heavens while the other is pointed towards a star more distant from the Pole than the Pole is from the horizon. This star will describe a part of its daily or diurnal circle above the horizon, and

part below it. Increase the angle between the legs of the compass, still keeping one extremity pointing towards the Pole, and a point will be reached when one leg is perpendicular to the other. Stars at this angular distance from the Pole are on the celestial equator. One half of their daily circle of travel is performed above the horizon, the other half below it. They are the only bodies which rise due east and set due west all the year round. In England, stars north of the celestial equator rise north of east and set north of west, and stars south of the equator rise south of east and set south of west. The first class are longer above than below the horizon, when observed in our latitudes; in the second class the reverse is the case, for stars belonging to it are longer below the horizon than above it. A third class, included in the circle of perpetual invisibility, never appear above our horizon.

These observations are shown in Fig. 216, which illustrates the condition of things for the latitude of London. All the stars within a circle at a distance of $51\frac{1}{2}°$ (this being the latitude of London) from the North Celestial Pole, are circumpolar, and stars within a circle at the same distance from the South Celestial Pole never appear above the horizon. Stars situated in regions of the celestial sphere between these two circles describe part of their apparent diurnal paths above the horizon and part below. A star on the celestial equator evidently describes half its diurnal circle above the horizon and half below.

Apparent diurnal movements of stars in different latitudes.—People unacquainted with the movements of the earth often assume that the apparent movements of stars are the same when viewed from any place on the earth, but, as has been explained, this is not the case. The changes in the sky first noticed by an observant traveller journeying southwards from middle latitudes for a considerable distance, is that the Pole Star sinks towards the northern horizon, while other stars make their appearance in the south. The oblique paths familiar to all who watch the heavens become more and more upright until, to an observer at the equator, all the stars are seen to rise straight up on the eastern horizon and to set in a similar manner in the western. The Pole Star will be on the horizon. If the journey is made from middle latitudes towards the Arctic regions, instead of towards the equator, a different appearance is again presented night after night—the Pole Star

appears higher above the horizon. The circle including the circumpolar stars thus daily increases in size. Stars which were observed to rise and set in the southern sky disappear, while others which described part of their daily circle below the horizon rise to the position of those which never set. And, if the North Pole were reached, the observer would see the Pole Star over-

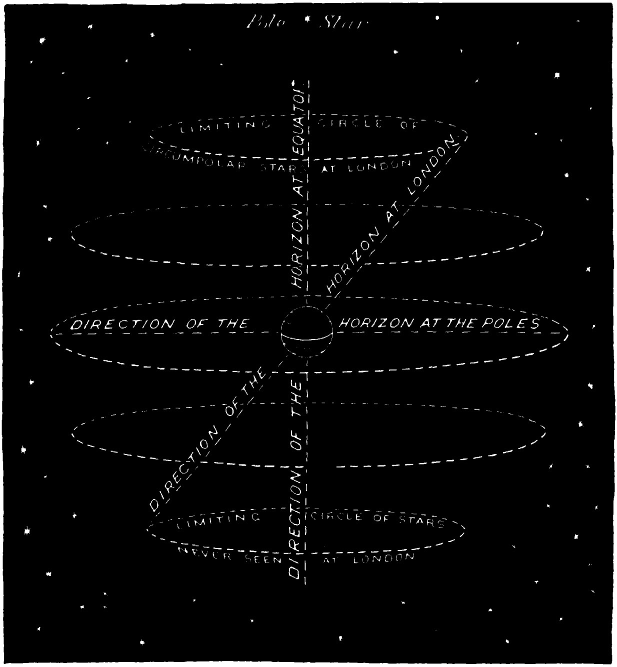

FIG. 217.—To explain the difference in the apparent diurnal motions of stars when observations are made in different latitudes.

head. All the stars would appear to travel round the celestial pole in concentric circles, the diameters of the circles increasing in size from this stationary point down to the horizon (Fig. 217).

Solution of questions referring to positions and diurnal movements of stars.—Though the apparent diurnal motions of the stars in different latitudes may appear complicated to students who have not had the time to observe or consider them,

they are really extremely simple, and every question as to the apparent position or motion of any star in any latitude can be easily answered by bearing in mind one or two facts. The best way to deal with all such questions is by means of diagrams. For any case, first construct a diagram, such as Fig. 218, showing the earth in relation to the celestial sphere, and some apparent diurnal circles. Next draw a line through the centre of the earth, and inclined to the axis at an angle equal to the latitude

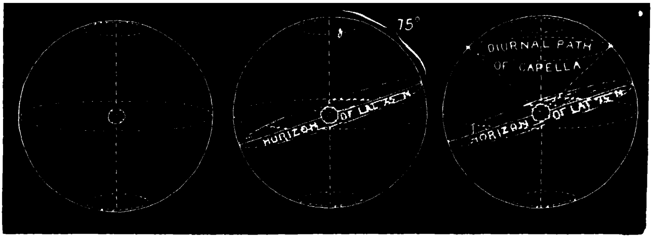

FIG. 218.—Stages in the construction of a diagram to show the apparent diurnal motion of Capella observed in latitude 75° N.

of the selected place of observation. This represents the horizon of the observer, and a perpendicular upon it at the position of the observer points to the zenith. Thirdly, if the position of a star is given, insert the star at its proper angular distance from the Pole, and draw a diurnal circle through the star parallel to the other diurnal circles. The diagram thus constructed exhibits graphically all the phenomena due to position and diurnal motion observable from the place selected. It is instructive to apply this method to an actual case :

Example.—An Arctic explorer spends Christmas in 75° north latitude. For 24 hours he watches the bright "fixed star" Capella, which in lat. 50° N. never seems to set though it sometimes appears close to the horizon. Describe the movements that the star seems to make. At about what altitude will he see the star (1) when it is nearest to the horizon, and (2) when it is highest above the horizon?

Draw the earth and one or two apparent diurnal circles on the celestial sphere (Fig. 218).

Insert the horizon of an observer in lat. 75° N., by drawing a line at an angle of 75° to the earth's axis.

As the star Capella is just circumpolar to an observer in lat. 50° N. its angular distance from the North Celestial Pole must be 50°; for latitude = altitude of Pole. Draw, therefore, the diurnal circle of a star 50° from N. Pole. It will then be seen that

Altitude of Capella when nearest the horizon $= 75° - 50° = 25°$.

Altitude when highest above the horizon $= 40° + 15° = 55°$

Models to illustrate apparent motions.—All the apparent motions of celestial bodies can be explained by the use of a celestial globe, but frequent use of such a globe is necessary before a student becomes familiar with it. A simpler instrument has been devised by means of which the apparent movements can be illustrated.[1]

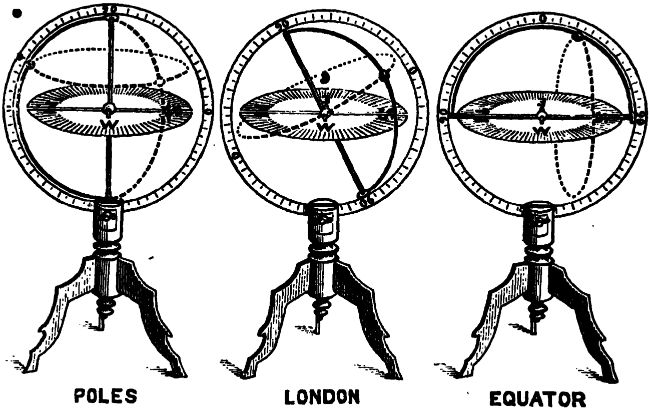

FIG. 219.—Model to illustrate the apparent diurnal of an object as seen from any latitude.

The instrument consists of a movable horizon, and an axis which can be set at any inclination to it. A small ball sliding upon a wire semi-circle is used to represent a celestial object. To use the instrument, the horizon is set horizontally, and the axis of the divided brass meridian is elevated until the angle it makes with the horizon is equal to the latitude of the selected place of observation. The small ball is then pushed along the wire until its angular distance from a celestial pole is the same as that of the object, the apparent motion of which is required to be illustrated. By rotating the wire semi-circle, the ball is thus made to describe a circle round the celestial pole, and the circle represents the apparent diurnal motion of the object with respect to the horizon of an observer in the latitude selected. The apparent diurnal motions of an object at a distance of about

[1]The instrument is termed "The Celestosphere," and is sold by Messrs. Chapman & Hall, Henrietta Street, Covent Garden, W.C.

70° from the North Celestial Pole, or 20° from the equator, as observed at the poles, in the latitude of London, and at the earth's equator, are represented in Fig. 219.

CHIEF POINTS OF CHAPTER XXV.

The visible horizon is the line, irregular or regular, where the earth and sky appear to meet. The *true* or *sensible horizon* is the line midway between the zenith and nadir of a place. The *rational horizon* is parallel to the sensible horizon, and the plane producing it passes through the earth's centre.

Altitude signifies angular distance above the horizon, measured in a vertical plane. Azimuth is angular distance from the true north or south point, measured in a horizontal plane.

The meridian of a place on the earth is a great circle passing through that place and the terrestrial poles.

The longitude of a place is the angular distance between the meridian of that place and a conventional meridian; *latitude* is angular distance north or south of the equator, or between the plumb-line at a place and the plane of the equator.

The relative positions of stars remain seemingly unaltered throughout the year, but the configurations change in centuries owing to the fact that each star is rapidly moving through space.

The heavens appear to rotate once in a little less than twenty-four hours round two points known as the celestial poles. The Pole Star is near the North Celestial Pole, but the position of the South Celestial Pole is not similarly distinguished.

The celestial poles are the two points in the sky possessing no diurnal motion; the celestial equator is midway between them.

The apparent motions of the stars differ in character when observed from different places on the earth. To a person at the equator the stars seem to rise straight up and set straight down; at the poles the stars describe circles parallel to the horizon; in middle latitudes there are (1) stars which never set; (2) stars which never rise; (3) stars which both rise and set.

A determination of latitude on the earth can be made by observing the altitude, or angular distance, of the pole above the north point of the horizon.

Right Ascension is analogous to terrestrial longitude, and is reckoned along the celestial equator from a certain point in the sky.

Declination is analogous to terrestrial latitude, and signifies angular distance north or south of the celestial equator.

EXERCISES ON CHAPTER XXV.

1. Sketch the relative positions of Arcturus and the stars in the Plough.

2. Make a sketch of the Plough and the Pole Star. Connect the Pointers with the Pole Star by means of a broken line. Upon the

same drawing, sketch the position of the Plough after an interval of six hours.

3. The altitude of the Pole Star is approximately equal to the latitude of the place of observation. Construct a diagram of the celestial sphere and the earth within it, to explain this relation.

4. In what positions is the Pole Star seen in Ceylon (lat. $7\frac{1}{2}°$ N.), Edinburgh (lat. 56° N.), and Spitsbergen (lat. 78° N.)?

5. The North Celestial Pole is $51\frac{1}{2}°$ above the north point of the horizon of London, and 90° from the celestial equator. What is the altitude of the celestial equator above the south point of the horizon. (Ans. $38\frac{1}{2}°$.)

6. At what points on the horizon does a star on the celestial equator rise and set?

7. In what position on the earth would it be possible for an observer to see the complete north celestial hemisphere?

8. Explain, by diagrams, why, to an observer in England, some stars are always visible on a fine night, some are never seen, and some rise and set.

9. Do the stars which rise due east pass near the zenith at London If not, how far are they from the zenith when they cross the meridian? (Ans. $51\frac{1}{2}°$.)

10. The bright star Vega is about 40° north of the celestial equator. An Arctic explorer observed it when due north below the Pole Star, and found its altitude to be 25°. In what latitude was this observation made? (Ans. 75°.)

11. Observing in London (lat. $51\frac{1}{2}°$ N.) a star was seen at an altitude of $21\frac{1}{2}°$ above the north point of the horizon. What is the angular distance of this star from the celestial equator? (Ans. 60°.)

12. An eminent writer describes how a man who had fallen down a pit was comforted by seeing a star which shone upon him throughout the night. Would it be possible for this to happen?

13. It is often said that all the stars appear to move from east to west. Is this strictly true? What observations would you suggest to test it?

14. When looking at a certain group of stars one evening, after an interval of three hours, I noticed that they had apparently moved towards the east, while another group had moved towards the west. In what direction was I looking, and how were the groups of stars situated with reference to the Pole Star?

15. Explain the lines:

> "Constant as the northern star,
> Of whose true-fix'd and resting quality
> There is no fellow in the firmament."

16. Sketch the positions of the stars referred to in the following lines from "Othello":

> "Seem to cast water on the burning Bear,
> And quench the Guards of the ever-fixed Pole."

17. What particular star is referred to in the following lines?

> "Whose light, among so many lights,
> Was like that star, on starry nights,
> The seaman singles from the sky
> To steer his bark for ever by."

How is it possible to steer a ship by means of a star?

18. The idea conveyed by the following lines is not exactly correct. Point out the inaccuracy.

> "As still to the star of his courtship, though clouded,
> The needle points faithfully o'er the dim sea."

19. Vergil, as rendered by Dryden, says:

> "Around our Pole the spiry Dragon glides,
> And like a wandering stream the Bear divides."

Comment upon these lines.

20. Is it sufficient to determine the altitude and azimuth of a celestial body in order to locate its position? If not, what other observation should be made?

21. Explain the meaning of *zenith*, *altitude*, and *azimuth*.

22. Describe clearly how angles are measured, and how you would determine roughly the altitude and azimuth of a celestial object.

23. Make a sketch, showing the relative positions of the Plough, Cassiopeia's Chair, the Guards, and the Pole Star.

24. Observing in London, a certain star was found to have an altitude of about 51° and an azimuth of 180°. Are these measures sufficient to enable a person to know what star was observed? If so, give the name of the star.

CHAPTER XXVI.

THE ROTATION OF THE EARTH AND ITS CONSEQUENCES.

90. APPARENT DAILY MOTION OF SUN.

i. **Determination of true north and south by the sun.**—(*a*) Fix a rod upright in a place where the sun can shine upon it. Two or three hours before mid-day observe the direction and length of the shadow of the rod, and by means of a piece of string fitting loosely upon the rod draw an arc of a circle having a radius equal in length to the shadow (Fig. 220). In the afternoon, when the shadow has the same length as in the morning observation, mark its direction. A line bisecting the angle between the directions of the morning and afternoon shadows is a true north and south line, and, if it could be continued in both directions, it would pass through the north and south poles.

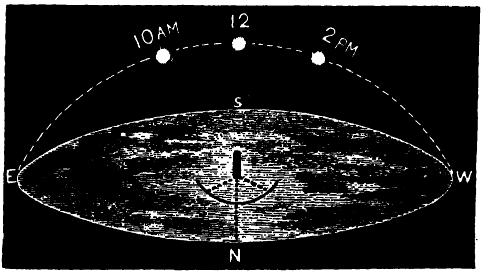

FIG. 220.—To illustrate how to draw a true north and south line by the sun.

(*b*) Notice that the length of the shadow decreases until mid-day, and then increases until the sun sets. The shadow is shortest when it lies due north and south, that is, when the sun reaches its highest point for the day.

ii. **Experimental illustration of the sun's diurnal motion.**—The observations of the change of position of the shadow of a rod upon

which the sun is shining must extend over several hours, but the fact they illustrate can be shown by fixing a rod upright upon a table, and using a small lamp to represent the sun. The lamp should be moved in an arc as the sun appears to do, that is, it should be steadily lifted above the edge of the table representing the eastern horizon, carried to the south, and then down towards the opposite edge. The change in direction of the shadow on a sundial during the day can thus be imitated. The method of finding a north and south line by bisecting the angle between two shadows of equal length before and after noon can also be demonstrated.

iii. **Length of apparent solar day.**—Notice the time when the shadow of an upright rod lies due north and south on any day. Make the same observation on the following day and several other days. In this way, find the number of hours between two successive appearances of the sun due south. The result gives the length of the *apparent solar day* at the time of year in which the observation is made.

iv. **Length of sidereal day.**—Fix the instrument shown in Fig. 206, or a similar one, so that the vertical circle lies in a north and south plane, and therefore any object can be seen through the tube or along the pointer when the object is in the south. Observe a bright star through the tube, and notice the time when the star is at the centre of the field of view. Let the instrument remain fixed in this position, and again observe the time at which the star occupies the same place in the field of view on the following evening, or several evenings later. From the observations determine the interval of time between two successive appearances of the star in the same part of the sky, that is, the length of a sidereal day expressed in ordinary clock time.

The sun as an object upon the celestial sphere.—It has been explained in the previous chapter that the apparent motions of all the stars are due to the rotation of the earth upon its axis. Each star may be regarded as a fixed point upon the celestial sphere, and its apparent diurnal path depends upon its position in the heavens and the latitude of the observer. Now, for the present, the sun may be considered as an extremely bright star having a certain position upon the celestial sphere. In the course of this chapter it will be shown that this position changes day by day, but for a single day we may, for the sake of simplicity, regard the sun as a very brilliant fixed star. The apparent diurnal motion of the sun is thus the same as that of a star occupying the same position upon the celestial sphere. There is no new condition, for the apparent rising and setting of the sun is due to the rotation of the earth in precisely the same way that the apparent movements of the stars are due to the same cause. Briefly, the apparent diurnal path

described by the sun depends, as does the apparent path described by a star, upon (1) the position in which the sun happens to be, and (2) the latitude of the observer. The only difference is that, when the sun is above the horizon, all the stars above the horizon at the same time are invisible on account of the overpowering glare of sunlight in our atmosphere.

The apparent daily motion of the sun.—Every day the sun appears on the eastern horizon, rises higher and higher in the sky, and reaches its highest position at noon, after which it sinks lower and lower until it sets. The varying elevation or altitude of the sun during the day can be seen by noticing the lengths of shadows. In the morning the shadow of an upright rod gets shorter and shorter until noon, when its length is least for that day. From noon the lengths of shadows increase until sunset. When the sun is at its highest position for the day it is due south, hence the shadows of objects at that instant lie due north and south. The line passing through the shadow of an object at noon if continued in both directions would reach the poles of the earth. Such a line would therefore be the meridian of the place in which the shadow lies.

When the sun rises in the east the shadows of objects point towards the west, and as it travels towards the south the shadow moves northwards until, when the sun is due south or at his highest altitude, and is passing over the meridian of the place, the shadow points due north. The westward journey of the sun throughout the latter half of the day is accompanied by a corresponding eastward motion of the shadow. The interval of time between the sun's highest position on any one day to its corresponding position on the next succeeding day is an *apparent solar day*. For a reason which need not here be explained the apparent solar day is *not* the same length as the day determined by the stars.

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91. CONSEQUENCES OF THE EARTH'S ROTATION.

i. **Experimental illustration of rotation.**—Place a small globe or ball upon a table. Stick a long pin into the globe in any position. Rotate the globe on its axis so that the northern hemisphere moves in the opposite way to the motion of the hands of a watch. Notice that the pin is turned in succession towards different objects upon the walls, floor, and ceiling of the room, which may be regarded as stars on the celestial sphere. If the globe rotated at a uniform rate,

the period of rotation could evidently be determined by observing the interval between two successive appearances of any one star in the same position.

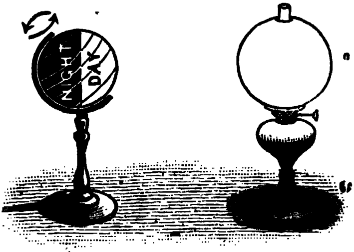

FIG. 221.—Experiment to explain the cause of day and night.

ii. **Day and night.**—Light a lamp to represent the sun, and place the globe near it. One half of the globe is illuminated, and the other hemisphere is in darkness. Rotate the globe as before; different parts are thus successively turned into the light and darkness. The rising and setting of the sun can thus be shown to be explained by the rotation of the earth on its axis from west to east.

The earth's period of rotation.—If a bright star is observed when looking towards the south-east on a very fine night, it will be seen slowly to climb higher and higher in the sky, until it reaches a certain point, and then as gradually to sink towards the western horizon. When at the highest point, the star is due south, and if the interval between the *southings* or *transits* on two successive nights is observed, it will be found to be 23 hours 56 minutes. This, then, is the length of a star-day—a day measured by the apparent movements of the stars. No matter what star is observed, the interval between two successive southings of it is exactly the same. Indeed, from the condition of things such a result is to be expected. The stars surround the earth on all sides. Consider them as the eyes of celestial spectators seated in a vast amphitheatre and watching the motions of our globe in the centre. Single out one of the spectators for observation, and suppose that, in consequence of the rotation of the earth, he is just coming into view. As the spin goes on, he becomes more and more visible, and eventually is directly in front of us. We are then turned away, and he appears slowly to pass in the opposite direction until he becomes invisible. Fresh faces are seen, but after a time the same person again appears, and goes through the same apparent movements. There is no difficulty in understanding that it is quite immaterial which individual is selected for observation, if we wish to find the length of a period of rotation. The time is noted at which the selected one passes in front of the place of observation, and then again noted when he once more occupies

the same apparent position. The interval between the two times is the required length. The rate at which the earth rotates, or the time taken to make one complete spin, is thus determined by observation of the stars.

Day and night.—The sun and the earth are bodies in space; the former is luminous, while the latter is a dark body with no light of its own. The sun sheds its light in every direction, and illuminates that half of the earth which is nearest to it, the remote half meanwhile being quite in the dark (Fig. 221). Were the earth at rest this would be the permanent condition of things, one half would always be illuminated or enjoy the brightness of day, the other would be in the perpetual darkness of night. But since the earth is rotating, new parts of our planet are being continually brought "out of darkness into light." The night is regularly followed by the day, and as the spinning carries any place round, it is in due course taken out of the sunshine into the shadow of evening again.

Dawn and twilight.—Before the sun appears on the eastern horizon, the light of dawn is seen, and for a short time after it has set, twilight occurs. These phenomena would not occur if there were no atmosphere, and they would be of longer duration if the atmosphere were more extensive than it actually is. In the morning the upper layers of air receive the light of the sun before the sun is really above the horizon, and the illumination of these layers causes dawn. In the evening, after the sun has really disappeared, the upper atmosphere is receiving its rays, and providing the appearance of twilight. In a similar way, during the day, sunlight is diffused by innumerable air-particles, enabling us to enjoy light when the source is hidden by clouds. Thus the cause which prevents us seeing the sun in the day on a star-spangled sky is the same as that which increases the length of the day by producing the phenomena of dawn and twilight.

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92. LONGITUDE AND TIME.

i. Greenwich and local times.—Cut out a ring of cardboard large enough to completely encircle a ball or globe with one or two inches between the inner rim and the surface of the sphere. Mark 24 divisions around the ring to represent hours, and number them from i. to xii. in each half of the ring, letting the numbers read in the opposite direction to those upon the dial of a clock. Place the sphere near a lighted lamp, with its axis vertical, and fix the ring on

a level with the equator so that one number xii. is directed towards the lamp. Stick a long pin into the globe at the equator on the meridian passing through Greenwich. This pin will serve to show the hour division over the Greenwich meridian at any time. Rotate

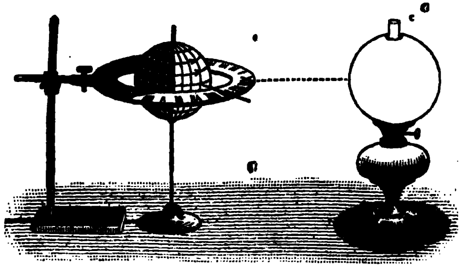

Fig. 222.—Model to illustrate the relation between time and longitude.

the globe and notice (1) that the Greenwich or any other meridian passes in succession under each of the twenty-four hours marked upon the ring; (2) that the time of day at any place depends upon the position of the place with reference to the sun; (3) that knowing Greenwich time, as shown by the pin, and the time at any place at the same instant, the longitude of the place can be determined.

Measurement of time by the sun.—The times of rising, southing, and setting of the sun and stars is different in places

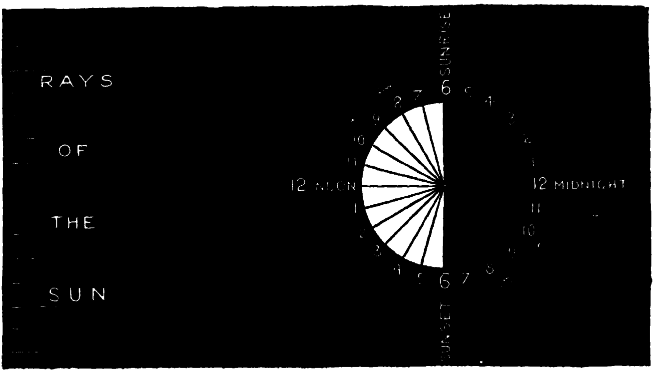

Fig. 223.—Relation between time and longitude.

situated on different meridians. This is because the earth is a spinning globe. In Fig. 223 the northern hemisphere of the

earth is represented as seen by an observer looking down upon it, the centre of the circle being the north pole. The meridians are 15° apart, so that there are 24 in the circle of 360°. The outer ring represents an imaginary dial fixed with the number 12 (noon) pointing at the sun. As the globe spins round, each meridian in turn occupies the position of that one marked "12 noon." An observer in this position will see the sun in his highest position for the day, or on the meridian, that is, southing. The observer situated on the opposite meridian will be as far away from the sun as he can possibly be. Or, to take an example, at places in longitude 180° it will be twelve o'clock midnight when it is twelve o'clock noon at Greenwich. When the sun is on the meridian at Greenwich, it will be six o'clock in the morning and six o'clock in the evening respectively at places 90° W. and 90° E.

Again, when it is twelve o'clock noon at Greenwich, at places 15° W. longitude it will be 11 a.m., while at places 15° E. longitude the sun has passed the meridian an hour ago, or it is 1 p.m.

Hence, we get a rule for knowing Greenwich time at a place when we are aware of the local time and the longitude of that place. If we are west of Greenwich we add to the local time one hour for every 15° of longitude or four minutes for every degree; while, if we are to the east we subtract the same amount. Similarly, if we already have Greenwich time, and we wish to know the local time, we can, being aware of the longitude, subtract the same amount for places west of Greenwich and add it for places of east longitude.

These facts are most useful in enabling navigators to determine their longitude. If the mariner has with him an accurate chronometer keeping Greenwich time, that is, which records twelve o'clock when the sun is on the meridian of Greenwich, he can by noting the time of southing of the sun, which happens at twelve o'clock noon local time, tell the difference between local and Greenwich time. If the local time is behind Greenwich time, his longitude is west, and equal to a number of degrees obtained by reckoning 1° for every four minutes it is slow. If the local time is ahead of Greenwich he is in east longitude, and on the meridian which is found by dividing the amount he is fast in the same way.

93. SUNDIALS.

i. **Construction of a sundial.**—Obtain a small slab of wood, about a foot square, and varnish the top so that a circle can be drawn upon it in ink, or glue paper upon it, and varnish the paper. Draw a diameter of the circle, and place the slab so that this line is due north and south and the sun can shine upon it. Fix a knitting-needle at the centre of the wood and inclined to it towards the north at an angle equal to the latitude of the place of observation. The needle then points towards the North Celestial Pole and is parallel to the earth's axis. Notice the position of the shadow of the rod at definite hours, say 9 a.m., 10 a.m., 11 a.m., noon, 3 p.m., 4 p.m. Draw a line from the centre of the circle in the direction of the shadow at each observed time. You will notice that the shadow does *not* move through the same angle every hour. In our latitude, therefore, the dial of a sundial must not have the hours marked at equal intervals like the hours on the dial of a clock.

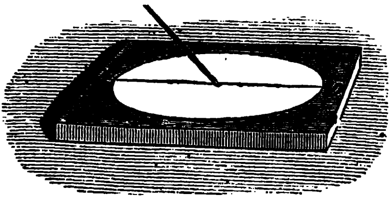

FIG. 224.—Simple horizontal sundial.

ii. **Diurnal motion of the sun at the poles.**—Draw a circle upon paper or thin cardboard, and divide it into 24 equal parts by drawing lines 15° apart from the centre to the circumference. Number these lines from i. to xxiv. to represent hours. Fix the circle upon a board or table and stick a knitting-needle or thin rod upright at its centre. Place a lamp so that the shadow of the needle can be clearly seen. Carry the lamp round the needle in the way indicated in Fig. 225 and notice the change of direction of the shadow of the needle. The sun appears to move round the heavens parallel to the horizon in this way at the poles.

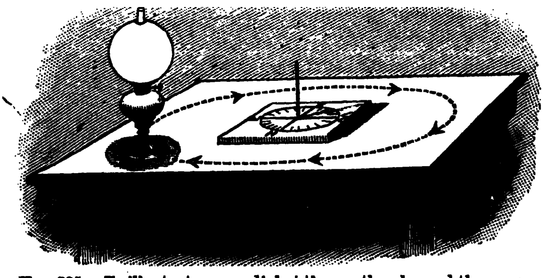

FIG. 225.—To illustrate a sun dial at the north pole, and the apparent diurnal movement of the sun there.

iii. **Construction of sundial for any latitude.**—Cut out of cardboard another circle of the same diameter as that in the preceding experiment, and push the knitting-needle through its centre. Incline this upper circle so that the knitting-needle makes an angle with it equal to the latitude of the place for which the dial is to be divided. Fix the circle in this position by means of a clamp of a retort-stand or in any other convenient way. Place a set square vertically against each of the 24 divisions of the lower circle, and make a mark where it touches the upper one. Now take off the upper circle and draw a line from each mark so obtained to the centre of the circle. These lines represent the hours, the one which was at the lowest part of the card being 12 midnight, and the opposite one 12 noon.

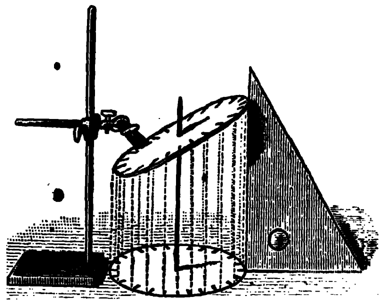

FIG. 226.—How to graduate a sundial for any latitude.

Sundials.—Though the time of day can be approximately estimated by noticing the direction of the shadow of an upright object, a properly constructed sundial is necessary if apparent solar time is to be accurately shown. The face of a sundial, upon which the hours are marked, is the dial, and the rod, the shadow of which falls upon the dial when the sun is shining, is the *style* (Fig. 227). The dial of a sundial is usually either horizontal, or vertical, and facing south. It may, however, be inclined at any angle and face any direction, provided that the style lies parallel to the direction of the earth's axis. The line showing the hour of twelve noon on the dial must also lie in the plane of the meridian of the place in which the sundial is fixed.

As the altitude of the Pole depends upon the latitude, the inclination of the style with regard to the horizon must also vary. For a horizontal dial, the style must be inclined to the dial at an angle equal to the latitude of the place. But whether the dial be vertical, horizontal, or inclined at any angle, or whether it faces north, south, east, or west, the style should be directed to the poles of the celestial sphere.

A sundial which has the style parallel to the earth's axis, and a dial parallel to the plane of the equator, represents the simplest

condition of things. Such a dial may be divided into 24 equal parts by lines drawn from the centre to the circumference, and the shadow will pass from one line to the next every hour. This would be the kind of sundial to use at the poles, where a vertical rod is parallel to the earth's axis and a horizontal board is parallel to the plane of the equator.

FIG. 227.—A sundial. Reproduced by permission of Messrs. Newton & Co., Fleet Street, E.C.

A sundial in any latitude could, of course, be arranged with the dial parallel to the equator and the style in the direction of the earth's axis, and in this case the hours would be separated by equal intervals. It is, however, more convenient to use a horizontal or vertical dial.

Construction of sundials for any latitude.—At the poles a vertical rod lies in the same direction as the earth's axis, and a horizontal circle is parallel to the equator. As the earth turns on its axis at a uniform rate, the apparent daily motion of the sun is also uniform, and the shadow on a horizontal dial changes its position at the uniform rate of 15° per hour.

If 24 meridians of longitude are considered to be drawn upon a terrestrial globe, then, in consequence of the earth's rotation, the sun passes from one meridian to the next, that is, through 15° of longitude every hour. Imagine the earth to be trans-

parent, like glass, and these meridians to be metal wires upon it. Imagine also that the earth's axis, instead of being merely a name, consists of a steel rod running from pole to pole, like a knitting needle through an orange. To an observer at the poles of this glass globe the meridians could be regarded as the lines on the dial of a sundial and the shadow a prolongation of the axis as the shadow of the style.

Bearing these assumptions in mind, it is easy to understand how to divide the dial of a sundial for any latitude. The meridians in Fig. 228 represent the hours of the day. The horizon of the selected latitude is drawn at its proper inclination to the equator, that in the diagram being the horizon of a place in the

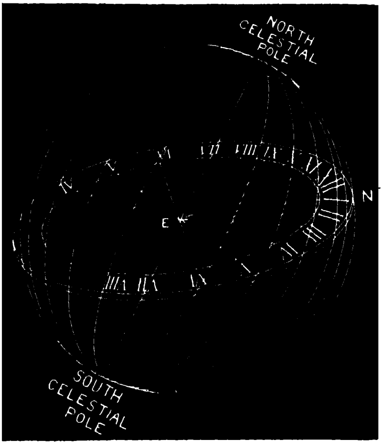

FIG. 228.—To illustrate the principle upon which sundials are graduated.

latitude of Edinburgh. Lines are drawn from the hours on the equator to the centre of the selected horizon, and are marked with the corresponding numbers. The divisions thus obtained represent the hours on a horizontal sundial for the place chosen.

CHIEF POINTS OF CHAPTER XXVI.

Daily variations of sun's altitude.—From rising, the sun's altitude increases to noon, when it is greatest; it then decreases until the sun sets. On this account the length of the shadow of an upright pole diminishes up to noon, when it is shortest, and then increases

until sunset. *True noon* occurs when the sun is due south, or at the point of maximum altitude for the day.

An apparent solar day is the interval between two successive transits, or southings, of the sun across the same meridian; it varies in length.

The sidereal day is the interval between two successive transits of a star across the same meridian; it always has the same length.

A mean solar day is the interval between two successive transits of an imaginary, or "mean" sun, over the same meridian; its length is the average of all the apparent solar days in a year.

Greenwich mean time is time reckoned with reference to the imaginary transit of the "mean" sun over the meridian of Greenwich Observatory. At the moment of transit, clocks and watches keeping Greenwich time should indicate twelve o'clock.

Relation between time and longitude:

Longitude.	Time.
15″	1 second
1′	4 seconds
15′	1 minute
1°	4 minutes
15°	1 hour
90°	6 hours

When it is noon at Greenwich, it is forenoon (a.m.) at westward places and afternoon (p.m.) at eastward.

Sidereal time is time reckoned with reference to the stars, or, more correctly, with reference to a particular point in the sky, known as the vernal equinox.

Apparent time is time reckoned with reference to the true sun; it is indicated by sundials, or "First Point of Aries."

The earth spins or rotates like a top, taking 23 hours 56 minutes to perform one rotation. The axis of rotation coincides with the shortest diameter, and the poles are at its extremities.

The apparent motion of the heavens from east to west, in consequence of which celestial bodies rise, south, and set, is a reflection of the earth's real motion in an opposite direction.

The reason why stars are invisible during the day, except a telescope is employed, is that the glare of sunlight in the earth's atmosphere overpowers their faint rays.

Dawn and twilight are caused by the sun illuminating the upper regions of our atmosphere. The phenomena would not occur if the earth were without an atmosphere, and would last longer if the atmosphere were increased in height.

EXERCISES ON CHAPTER XXVI.

1. Describe a sundial, and show how dial time differs from local time. (1896.)
2. State the apparent daily movements at London of stars situated near north declination 90°, 51°, 39°, on the equator, and near south declination 20° and 38°. (1895.)
3. What is sidereal and what is mean time? (1892, 1895.)

4. What differences occur in the apparent paths of the stars across the sky as we proceed from the equator to the Pole? What is the cause of this difference? (1889.)

5. Explain the relation between longitude and time. When it is noon at Greenwich, what time is it at a place in 30° west longitude?

6. How would you draw a true north and south line by observations of the sun? How could you use such a line in the determination of the length of an apparent solar day?

7. How is the earth's period of rotation determined?

8. Dawn and twilight are produced by the earth's atmosphere. Reasoning from this fact, would you expect these phenomena to be of longer or shorter duration near the equator than in middle latitudes? Explain the grounds of your conclusions.

9. Will a sundial which has been made for a place in London also be suitable for Edinburgh? If not, why not?

10. A gentleman had a horizontal sundial sent to him, and wished to know whether it was suitable for the place he lived in, and if so, how to set it up. Write a description telling him what to do.

11. If you were ordering a sundial for a south wall, what particulars would you give the maker? and how would you test the sundial supplied?

12. Why is it necessary for the style of a sundial to be parallel to the earth's axis?

CHAPTER XXVII.

THE REVOLUTION OF THE EARTH AND ITS CONSEQUENCES.

94. THE ECLIPTIC.

i. **Apparent eastward motion of the sun.**—(*a*) Notice any conspicuous stars or constellations visible in the western sky about an hour after sunset for several weeks or months. Constellations which are high above the sun at the beginning of the observations will gradually appear lower and lower, and will finally set with the sun.

(*b*) Notice the constellations visible when looking south at a particular hour at different times of the year. The constellations visible at, say, ten o'clock at one time of the year will be found in the south-west at the same time about six weeks later, and will be setting at that time three months after commencing the observations.

ii. **Determination of the ecliptic.**—Obtain a piece of squared paper and divide it in the way represented in Fig. 229. The middle long line represents the celestial equator, and the lines north and south of it are "parallels of declination." The twenty-four short lines should be numbered to represent the twenty-four lines of "Right Ascension" upon the celestial sphere.

The table given on p. 366 shows the Right Ascension and Declination of the sun near the middle of each month. Make a mark upon the chart to locate each position shown in the table. Draw a curve through the points thus formed; this curve represents the apparent path of the sun among the stars, that is, the *ecliptic.*

Apparent annual motion of the sun.—The apparent daily motion of the sun is known to everybody, but there is an apparent yearly motion which is detected only by the observant. In the evening, when the sun has set and night has come, certain groups of stars or constellations will be seen above the western horizon, other groups will be southing, and still other groups will be found in the east. If the sky is watched at the same time every night, in a few days the stars which were seen

well above the western horizon at the end of twilight are lower down; while those that were due south appear nearer the west, and those that were on the eastern horizon are seen above it. In the course of a few weeks the stars which were seen above the western horizon just after sunset will be invisible; those which were on the eastern horizon will be high above it, and other stars will have taken their place. In about six months after the first observation, stars which were on the eastern horizon will appear on the western horizon at the same time; and, in a year, the sky presents the same appearance as formerly. It seems, therefore, from these observations that the sun apparently moves among the stars in an eastward direction, and makes a complete circuit of the heavens in a year.

The ecliptic.—Near the equator, where twilight only lasts for a short time, the stars become visible very soon after the sun has disappeared below the horizon. The constellations near the sun at sunset are therefore more easily distinguished than in middle latitudes. If they are noted night after night, the apparent yearly

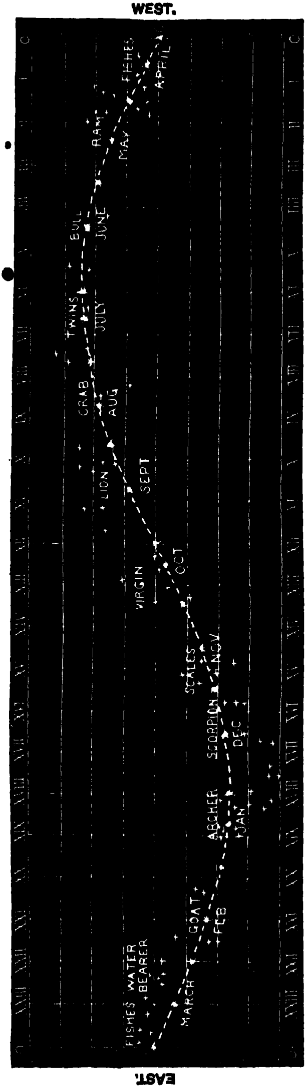

FIG. 229.—The ecliptic, or apparent annual path of the sun among the stars.

path of the sun among the stars can be found. The accumulation of such observations showed early astronomers that the sun was always accompanied by a particular star-group at a particular time of year; in other words, the sun does not appear to pass through one set of stars at a given time in one year and another group at the corresponding time in another year, but keeps to a fixed track, which is called by astronomers the *ecliptic.* Whatever part of the ecliptic the sun occupies, the stars in the neighbourhood are invisible, for, when an observer is turned towards that part of the heavens the sun is above his horizon, and the light of the stars is lost in sunlight glare. As, however, the sun apparently travels completely round the celestial sphere in a year, different groups of stars are thus rendered invisible at different times of the year.

Position of the ecliptic.—Remembering that the position of any celestial object can be defined by means of the coordinates Declination and Right Ascension, just as definitely as the position of a point in the earth can be defined by latitude and longitude, a method of determining exactly the apparent annual path of the sun can be easily understood. All that it is necessary to do is to determine the Declination and Right Ascension of the sun at a number of times throughout a year, and to plot the points thus obtained upon a chart having lines representing Declination and Right Ascension drawn upon it. The following table shows the Right Ascension and Declination of the sun at noon near the middle of every month:

Date.	Right Ascension of Sun at Noon. H.	M.	Declination of Sun at Noon.	Remarks.
Mar. 21 . .	0	1	0° 0′	**Spring Equinox.**
Apr. 15 . .	1	36	10° 3′ N.	
May 15 . .	3	31	19° 3′ N.	
June 20 . .	5	58	23° 27′ N.	**Summer Solstice.**
July 15 . .	7	41	21° 25′ N.	
Aug. 15 . .	9	41	13° 50′ N.	
Sept. 23 . .	12	3	0° 0′	**Autumn Equinox.**
Oct. 15 . .	13	23	8° 49′ S.	
Nov. 15 . .	15	25	18° 42′ S.	
Dec. 21 . .	18	1	23° 27′ S.	**Winter Solstice.**
Jan. 15 . .	19	47	21° 10′ S.	
Feb. 15 . .	21	54	12° 44′ S.	

When these values are plotted upon a chart, a curve can be obtained like that in Fig. 229. This curve evidently represents the apparent annual path of the sun, that is, the ecliptic. It will be seen that the sun is north of the celestial equator for about six months of the year and south of it for the remaining six months.

Much can be learned from the table and Fig. 229. Consider first the column of the sun's Right Ascension at noon. On March 21, the sun is at the starting-point. It apparently moves eastward on the celestial sphere at the rate of about two hours of Right Ascension per month, and thus moves through the whole 24 hours in twelve months. Now look at the column of Declinations. On March 21, the sun is on the celestial equator. From that date it moves northwards, and on June 20 reaches its greatest northerly position, viz., about 23½° N. From June 20, the north Declination decreases until, on September 23, the sun is again on the equator. From September 23 the sun moves southwards, and on December 21 reaches its most southerly position, viz., about 23½° S. It then returns to the equator, and reaches the starting point on March 21.

95. THE ZODIAC.

i. **Constellations traversed by the sun.**—Notice in Fig. 229 the constellations lying in the neighbourhood of the ecliptic. Make a table showing the constellation behind the sun in each of the twelve months of the year. In what months is the sun in the constellations Pisces (Fishes), Cancer (Crab), and Capricornus (Goat)?

The apparent eastward motion of the sun.—In consequence of the apparent eastward motion of the sun among the stars, different constellations are visible at different times of the year. The sun's apparent path can be precisely traced throughout the year in the manner already described. Therefore, knowing the position of the sun upon the celestial sphere at any time, the stars or constellations which form the background are also known, for they are fixed points upon the celestial sphere. Those groups of stars which lie in the neighbourhood of the sun's track—the ecliptic—are known as zodiacal constellations, or constellations of the *Zodiac*, the Zodiac itself being a zone extending completely round the heavens between the limits of about 9° or 10° north and south of the ecliptic. The positions of the signs of the Zodiac upon the celestial sphere are represented in Fig. 230.

The next illustration (Fig. 231) shows that the apparent annual journey of the sun through the various constellations of the Zodiac can be explained by the real motion of the earth around the sun in a year.

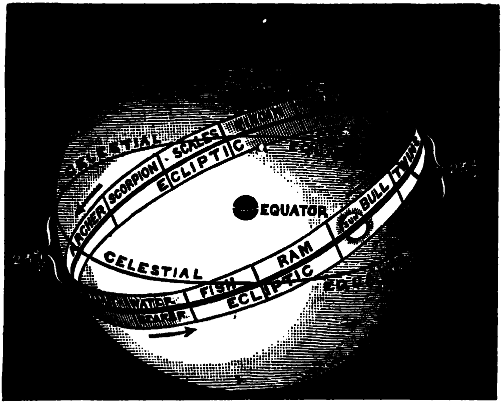

FIG. 230.—The signs of the zodiac upon the celestial sphere.

Signs and constellations of the Zodiac.—An examination of Fig. 229, or of the table of the sun's monthly positions on the celestial sphere (p. 366), will show that when the sun is projected upon the celestial equator (at the spring equinox, March 21), stars belonging to the constellation of the Waterer and the Fishes are in the corresponding background. At the end of April the sun has apparently passed through the Fishes constellation and enters the Ram constellation. From this it apparently passes successively through the various groups of stars near the ecliptic until the following March. Early astronomers considered the sun to be really moving among the stars, and they imagined its path divided into twelve equal parts, through each of which the sun took a month to travel. These parts were called *signs of the Zodiac*, and each was given a particular name. The names of the signs have been put into rhyme as follows:

The Ram, the Bull, the Heavenly Twins,
And next the Crab, the Lion shines,
The Virgin and the Scales;

The Scorpion, Archer, and He-Goat,
The Man that bears the watering-pot
And Fish with glittering tails.

These signs were regarded by the astrologers as if they were twelve equal divisions marked upon the vault of heaven, and the sun was like the hand of a timekeeper making a complete rotation around the celestial dial in a year. At the spring

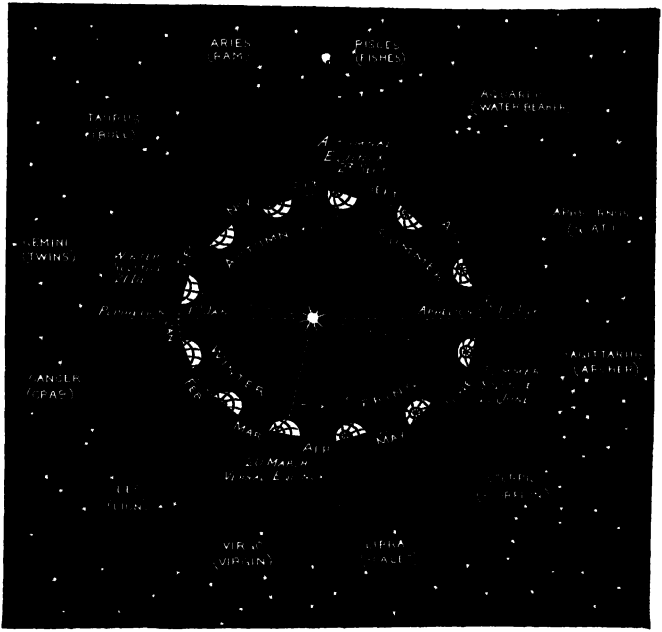

Fig. 231.—The earth in its orbit, in relation to the constellations of the Zodiac.

equinox (March 21) the sun entered the Ram sign; a month later it entered the Bull sign; and so on through all the twelve signs of the Zodiac. But observations such as are represented in Fig. 229 show that at the spring equinox the sun is not now projected upon the Ram constellation, but upon the Fishes group of stars. It is as if the dial of the old astrologers' zodiacal clock

had in the course of ages twisted round a little, so that though the hand has moved at the same rate the divisions on the dial reached by it at any particular time of year is not the same as it was formerly.

In spite of the fact that the signs of the Zodiac do not coincide with the zodiacal constellations, they are considered as twelve equal divisions of the Zodiac, starting from the point of the celestial sphere upon which the sun is projected at the spring equinox, as shown in Fig. 231. The point occupied by the sun on March 21 is still known as the "First point of Aries," though really the sun has not the constellation Aries (the Ram) behind it until the end of April. The explanation of this change belongs more to a text-book of astronomy than to this general survey of obvious phenomena.

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96. RELATION OF CONSTELLATIONS TO SEASONS.

i. **Constellations visible at different times of the year.**—Taking the space between two successive short lines in Fig. 229 to represent an hour, the constellation any number of hours east or west of the sun at any time of year can be seen. Find the zodiacal constellation which sets about three hours after the sun in May and November. Also find the constellation which is twelve hours distant from the sun at the present time of year—this constellation is due south at midnight.

Star seasons.—Referring again to Fig. 229 or 231 it will be understood that when the sun is projected upon any part of the heavens, the stars visible at night are those in the opposite celestial hemisphere. The sun is in the neighbourhood of the constellation of the Scorpion in December; the stars visible at that season of the year are therefore those in the opposite part of the heavens, such as the Bull, the Twins, and other constellations above and below them. Stars which are one hour east of the sun at any time of year rise, south, and set an hour later than the sun; while stars an hour west of the sun rise, south, and set an hour earlier. Hence, if the sun's position at any time of year is shown upon a chart or celestial globe, it is easy to find the stars which rise, south, and set any number of hours before or after the sun. Remembering this, it is easy to understand the appearance of different constellations at different seasons. In the winter months the most conspicuous constellation to be seen when looking towards the south is that of Orion.

Just when the days are beginning to lengthen, Orion appears due south at midnight. As spring approaches, the constellation apparently moves westward, and when this season has arrived the Orion stars are invisible at midnight, and the stars of Virgo (the Virgin) have taken their place. This is the time of year when

> The shining daffodil dies, and the charioteer
> And starry Gemini hang like glorious crowns
> Over Orion's grave, low down in the west.

In earlier times the appearance of the Virgin in the midnight sky served as an indication that sowing time had come. At the time when days are longest, the constellation of Hercules occupies the highest position at midnight. The autumn—the time for reaping—is announced by the appearance of Andromeda in the midnight sky, with Orion in the east; and winter again sees the conspicuous Orion's belt in its former place. The heavens thus serve to mark the succession of the seasons.

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97. REVOLUTION OF THE EARTH.

i. **Explanation of sun's apparent annual motion.**—Place a lamp upon a table to represent the sun, and a small globe near it to represent the earth. Various objects on the walls, floor, and ceiling of the room may be regarded as stars. Move the globe around the lamp, and notice that the object upon which the lamp as seen from the globe is projected, varies with the position of the globe. In taking the globe completely round the lamp in one plane, the lamp appears to make a complete circuit of the room as seen from the globe. This apparent change of position caused by the revolution of the globe illustrates the apparent annual motion of the sun among the stars.

Cause of sun's apparent eastward motion.—The apparent change of position of the sun upon the celestial sphere during the year would become actual if the sun really moved round the celestial sphere along the ecliptic, and took a year to make the complete circuit of the heavens. Proof can, however, be afforded that this is not the case, and that all the annual variations described are due to the fact that the earth, in addition to its regular rotation upon its axis, has another motion which carries it round the sun in a definite path, or orbit, once a year.

Consider the sun and earth in space, but at an infinite distance away, surrounded by the stars upon the celestial sphere. An observer facing the sun at any instant cannot see the stars

behind it. But on account of the earth's change of position as it travels round its orbit, the stars forming the background of the sun differ from month to month. The condition of things is exactly analogous to that in the case of a cyclist careering round a racing track in the centre of which we may suppose an electric light to be situated. Distant objects will appear in different directions with reference to the light, when observed by him from different points of the course.

In the same way the earth travels round the sun, and, as a consequence, the sun appears to be projected upon different star-groups at different times of the year. As the earth's track is a plane, the level of which is practically constant from year to year, the sun's apparent path through the stars undergoes no change as the years roll on. This path is termed *the ecliptic*, and it is evidently the line of intersection of the plane of the earth's orbit with the celestial sphere. In exact words, we may define the ecliptic as *the trajectory marked out by the sun in its apparent annual motion among the stars caused by the real motion of the earth in an orbit.*

CHIEF POINTS OF CHAPTER XXVII.

The sun appears to move in an eastward direction among the stars, thus producing the change in the constellations visible at midnight.

The ecliptic is the apparent annual path of the sun among the stars.

The zodiacal constellations are those situated within about eight or ten degrees of the ecliptic on both sides.

The signs of the Zodiac are the names of twelve equal divisions of the sun's apparent annual path among the stars. The point occupied by the sun at the vernal equinox is the "First Point of Aries," and from it the signs of the Zodiac are reckoned.

Equinoxes and solstices: Spring or vernal equinox, March 21; Summer solstice, June 20; Autumnal equinox, Sept. 23; Winter solstice, Dec. 21.

Changes of the sun's declination.—The sun only appears to be on the celestial equator twice a year—at the equinoxes. At the solstices he has his greatest north and south declinations.

Apparent annual movements of constellations.—The stars rise, south, and set four minutes earlier every night, so the constellations visible at midnight change throughout the year.

The earth's annual revolution around the sun causes the apparent annual movement of the sun among the stars.

EXERCISES ON CHAPTER XXVII.

1. How is it possible to use the heavenly bodies to mark seasons and years?

2. Suppose you were so situated that you were without clock or calendar in a part of the world where neither could be obtained. How would you be able to determine the time of day and year by the sun or stars?

3. Euripides, in one of his tragedies, makes the Chorus ask the time of day in the words "What is the star now passing?" and the reply is "The Pleiades show themselves in the east; the Eagle soars in the summit of heaven." Explain this question and answer.

4. Explain, as well as you are able, the astronomical significance of the following words from the book of Job: "Canst thou bring forth Sirius in his season?"

5. The Kids (Eta and Zeta Aurigae) were supposed by the ancients to have a bad influence on the weather. Thus, Callimachus says:

> "Tempt not the winds, forewarned of dangers nigh,
> When the Kids glitter in the western sky."

To what time of year do these lines refer?

6. How could you determine exactly the position of the ecliptic upon the celestial sphere?

7. If the earth revolved around the sun in a different plane from that in which it travels at present, what changes would this alteration produce in (*a*) the position of the ecliptic on the celestial sphere, (*b*) the constellations of the Zodiac, (*c*) the signs of the Zodiac?

8. Describe and explain the apparent movements of the stars to an observer, (*a*) in the British Isles, (*b*) at the equator, (*c*) at the North Pole.

9. A star is observed to be at a certain distance above the sun at sunset on a particular day. What difference would be observed a week later?

10. Describe observations which show that the sun has an apparent motion among the stars.

11. Describe and explain the sun's apparent annual motion among the stars.

12. Explain the following reference by Hesiod to the Pleiades:

> There is a time when forty days they lie,
> And forty nights concealed from human eye;
> But in the course of the revolving year,
> When the swain sharps the scythe, again appear.

13. Explain the following terms: ecliptic, equinox, solstice, meridian.

CHAPTER XXVIII.

ANNUAL VARIATIONS OF THE SUN'S POSITION WITH REFERENCE TO THE HORIZON.

98. THE SUN AT NOON.

i. **Length of noonday shadows.**—Observe the length of the shadow of a fixed object at noon at different times of the year. If possible, mark the length of the shadow of a post at noon on March 21, June 20, September 23, and December 21, that is, at the equinoxes and solstices.

ii. **Measurement of sun's noonday altitude.**—Fix a thin rod upright in a drawing board or slab of wood. Draw a line upon the

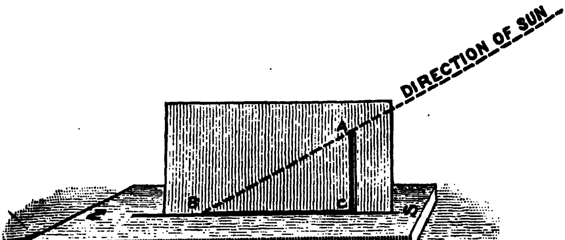

FIG. 232.—Method of measuring roughly the altitude of the sun at noon.

wood passing through the point in which the rod is fixed. Place the board out of doors, so that it is horizontal and the line upon it lies due north and south. When the shadow of the rod falls upon the line, that is, at noon, mark upon the board the point where the end of the shadow touches the line. Stand a piece of cardboard upright upon the north and south line, and mark upon it three points (1) at the bottom of the rod, C; (2) at the top of the rod, A; (3) at the point reached by the end of the shadow, B. Connect these points and measure the angle ABC with a protractor. This angle shows the altitude of the sun at noon on the day of the observation.

Annual variations of the sun's altitude.—The daily variation in the length of the shadow of a fixed object as the sun describes its daily arc in the sky has already been described. The noonday shadow is the shortest shadow for the day, but the observation of this shortest shadow day by day will show that its length varies throughout the year. In the summer the noonday shadow is comparatively short, and from midsummer to midwinter it gradually lengthens, while from midwinter to midsummer it gets shorter and shorter day by day.

The length of a noonday shadow indicates the altitude of the sun at noon, and from the altitude measured in this way, or by a proper instrument, the position of the sun with reference to the celestial equator can be found; for the altitude of the celestial equator above the south point of the horizon is equal to the angle that remains when the latitude of the place is subtracted from 90° (see p. 341). Therefore, knowing the altitude of the equator and the observed altitude of the sun, a comparison of the two values will show how the sun is situated with reference to the celestial equator.

Suppose the observation to be made on May 30 in latitude 58° N., and that the altitude of the sun at noon is found to be 47°. Then to find the position of the sun with regard to the equator we proceed as follows:

Latitude of place, ...	58° N.
∴ Altitude of equator, ...	$90° - 58° = 32°$
Altitude of sun at noon, . . .	47°
∴ Angular distance of sun from equator,	$47° - 32° = 15°$

The sun is thus found to be 15° above the equator, that is, 15° N. on May 30.

Diurnal paths of the sun at different times of the year.—As the position of the sun upon the celestial sphere changes from day to day, the sun has not a definite diurnal circle. Like a star, the apparent diurnal path of the sun on any day depends upon the sun's declination at the time. When the sun is 10° north of the equator, it has the apparent diurnal circle of a point on the celestial sphere in Declination 10° N.; when it is on the equator, its apparent diurnal circle is the same as that of a star on the equator, and so on, for any other position which it occupies. In consequence of this, the apparent paths of the sun across the sky differ at different times of the year (Fig. 233).

On the shortest day of the year, if the sun happens to be visible from rising to setting, it appears to describe a very small arc in the sky, and even at noon it is only a short distance above

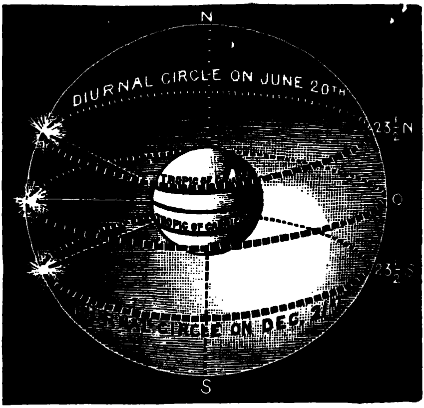

FIG. 233.—Positions of the sun on the celestial sphere at the equinoxes and solstices.

the horizon. Every day from midwinter the sun rises earlier and sets later, and is higher at noon than on the previous day. The arcs traversed increase until at the spring equinox the day is of the same length as the night, and the sun describes a semicircle above the horizon and a semicircle below it. The increase in the length of arc traversed goes on up to midsummer. Towards the end of June the highest noonday point is reached, and the sun appears to travel along almost the same path for two or three days. When this occurs, the *summer solstice* has come, the word *solstice* signifying that the sun stands still, instead of continuing his motion towards the north.

On midsummer day the sun is seen in its greatest elevation; to us in England it is almost, but not quite, overhead at midday. This fact needs emphasising, for the sun is commonly said to be directly overhead in midsummer. After the summer solstice the sun takes a downward course. Day by day its noonday height diminishes, and its time above the horizon decreases. Autumn is reached, and the day again becomes equal in length to the night, because the sun is on the equator, and therefore half its diurnal path is above and half below the horizon.

From the autumn equinox to midwinter day the sun gets more and more south of the equator every day, and its diurnal path is therefore that of a point south of the celestial equator. When the Declination of $23\frac{1}{2}°$ S. is reached, the sun's diurnal path is the same as that of a star or any other celestial object $23\frac{1}{2}°$ south of the equator. This is the lowest point reached—it is the turning point or *winter solstice*—and after apparently remaining in this position for a few days the sun appears to move northwards again.

99. THE SUN AT SUNRISE AND SUNSET.

i. Observation of the sun on the horizon.—Notice the bearing or azimuth of the sun at sunrise (or shortly after) and at sunset in different months, and more particularly at the equinoxes and solstices. The sun will only be found to rise due east and set due west at the equinoxes. From the spring equinox to the autumnal equinox it will be found to rise north of east and set north of west, and from the autumnal equinox it will be found to rise south of east and set south of west.

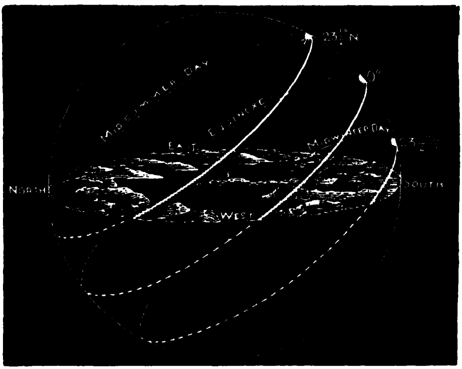

FIG. 234.—Diurnal circles of the sun at the equinoxes and solstices, in relation to the latitude of London.

Points at which the sun rises and sets.—The points on the horizon at which a star rises and sets are determined by (1) the star and its position with reference to the equator, that is, its declination; (2) the latitude of the place of observation. In precisely the same way, the positions of the sun at sunrise and sunset depend upon the sun's declination and the latitude of the

place of observation. If this is clearly comprehended, there is no difficulty in understanding that the points on the horizon at which the sun rises and sets undergo a yearly variation in agreement with the annual change of the declination. Consider the three most distinctive positions of the sun on the celestial sphere, viz.:

(1)	Declination on Midsummer Day, . .	23½° N.
(2)	,, at Equinoxes, ...	0°
(3)	,, on Midwinter Day, . . .	23½° S.

These declinations are the same in whatever position an observer of the sun may be situated. Now each of these points on the celestial sphere corresponds to a particular diurnal circle, as is represented in Fig. 234, and each of the three diurnal circles cut the horizon in particular points. In the latitude of London the points at which the circles cut the horizon are as follows:

Time of Year.	Sun's Declination.	Rising Points.	Setting Points.
Midsummer Day, .	23½° N.	40° N. of E.	40° N. of W.
Equinoxes, . .	0°	E.	W.
Midwinter Day, .	23½° S.	40° S. of E.	40° S. of W.

It is thus seen that the sun only rises due east and sets due west when it is on the celestial equator. It rises nearly north-east in London on midsummer day, and sets nearly at north-west. On midwinter day it rises nearly south-east and sets nearly south-west. In the course of the year the positions of the sun at sunrise vary between the limits shown, namely, from 40° N. of E. to 40° S. of E.; and its positions of setting vary in the same way from 40° N. of W. to 40° S. of W.

100. OBLIQUITY OF THE ECLIPTIC.

i. **Conditions for a constant noonday altitude.**—Place a lighted lamp upon a table, and near it a small globe or a tennis ball with a knitting needle through the centre, forming an axis. Arrange the globe or the ball with the axis perpendicular to the table, as in Fig. 222, and the equator on a level with the light of the lamp. Carry the globe around the lamp on this level, and notice (1) that the light, which represents the sun, is directly overhead at the equator in every position of the globe; (2) that the direction with reference to the zenith or horizon of a line from the light to any

place at noon, that is, when the place directly faces the light, depends upon the latitude, and is constant for any one latitude; (3) that during a complete spin of the globe every place faces the light for half the period of spin and is out of the light for the other half. The model thus illustrates that if the earth revolved round the sun with its axis perpendicular to the plane of its orbit, the sun would always have the same altitude at noon at any one place, and this altitude would depend upon the latitude of the place. Also, that day and night would be of equal length everywhere throughout the year.

ii. **Explanation of inclination of equator to ecliptic.**—Incline the axis of the globe or ball about 23½° out of the vertical, or 66½° to the level of the table. Let the top of the axis point upward to some mark or object on the ceiling of the room. Place the globe in the

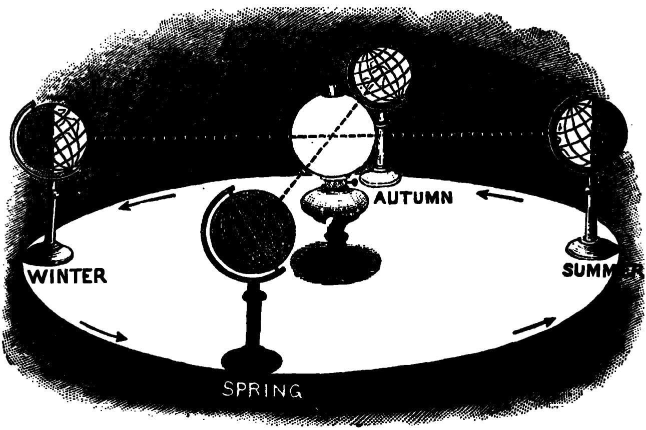

FIG. 235.—To explain how the annual changes of the sun's declination are produced by the inclination of the earth's equator to the plane of the ecliptic.

four positions represented in Fig. 235, the axis being kept pointing in a constant direction. Notice that (1) at our midsummer the light is directly overhead in latitude 23½° north of the equator (Tropic of Cancer); (2) at our midwinter it is 23½° south of the equator Tropic of Capricorn); (3) at the equinoxes it is directly over the equator. Carry the globe completely round the lamp to represent the earth's annual revolution round the sun. Notice that, on account of the inclination of the axis, the sun's apparent position varies gradually from 23½° north to 23½° south. At places between these two limits the sun is directly overhead at noon twice in the course of a revolution.

iii. **Explanation of variation of sun's noonday altitude.**—Stick a long pin into the globe in the position of London, so that it points upwards to the zenith. Place the globe successively in the four

positions of equinoxes and solstices as before, and in each case spin the globe so as to make the pin face the light, to represent the position at noon. Notice that (1) at the summer solstice the direction in which the light is seen at noon is not far from the zenith (this represents the high sun of summer); (2) at the winter solstice, the light is much nearer the horizon, or further from the zenith, of London than in summer; (3) at the equinoxes, the light at noon is seen in a direction midway between the extreme points of summer and winter. The annual variations of the sun's noonday altitude at any place can be explained similarly by the inclination of the earth's equator or axis to the plane of revolution around the sun.

Inclination of the earth's axis.—Although the phenomena due to the sun's apparent motion can be understood by considering the sun as a moving object upon the celestial sphere, this does not explain the cause of the annual variations already described. It has been shown that the earth is a globe revolving round the sun once a year, and spinning once a day on an axis passing from pole to pole through the earth's centre. The observations of the annual variations of the sun's noonday altitude enables the inclination of this axis to be determined.

Suppose the earth revolved around the sun with its axis perpendicular to the plane of its orbit, or to a line connecting the centre of the earth with the centre of the sun. If this condition of things actually existed, day and night would be of practically the same length in all parts of the earth and at all times of the year, for every place would be turned towards the sun for half a period of rotation and away from it during the other half. At any one place the sun would always appear to describe the same arc in the sky at all times of the year, and the size of this arc would depend upon the latitude of the place. But we know that these conditions of equality do not exist, and a critical study of the facts of observation show that they can only be satisfactorily explained by considering the earth to revolve around the sun with its axis inclined $23\frac{1}{2}°$ out of the vertical to the plane of its orbit.

Imagine a plane passing through the centre of the earth and the centre of the sun; the earth's centre will fall in this plane at all times of the year, that is, whatever the position the earth occupies in its orbit. This plane, containing the earth's orbit, is called the *plane of the ecliptic*. Or, putting the same fact in another way, we can think of the earth and sun as floating in a boundless ocean, each of them being half immersed, or

sunk as far as their centres. In these circumstances the surface of such an ocean would be the plane of the ecliptic. The earth would have to be supposed to float in such a manner that its axis made an angle of $66\frac{1}{2}°$ with the surface of the ocean, because the axis of the earth is inclined at an angle of $66\frac{1}{2}°$ to the plane of the ecliptic. The plane containing the earth's equator is known as the plane of the equator, and from the above inclination it follows that *the plane of the equator and the plane of the ecliptic are inclined to one another at angles of* $23\frac{1}{2}°$.

Some consequences of the inclination of the earth's axis.—The earth's axis, whatever the position of our planet on its orbit, is always inclined at the same angle to the plane of the orbit, and in the same direction. Or, at the various positions of the earth in its annual journey round the sun, the directions of the axis always remain parallel to one another. The axis always seems to point in the same direction in space, and the Pole Star is near the point in the sky to which the northern extremity is directed.

It is due to this inclination that the mid-day sun has a different altitude at different times of the year. Fig. 236 shows

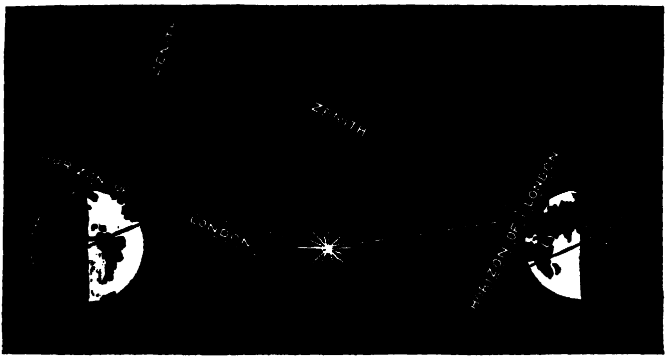

FIG. 236.—To explain the differences of altitude of the sun in summer and winter, as observed from London.

the positions of the earth at midwinter and midsummer respectively. At the former of these times, when the earth is in the left-hand position of the figure, the north pole of the earth's axis points away from the sun as shown. To an observer at

London it is clear that the sun will appear very near the horizon. When, six months after, the earth has reached the right-hand position in the figure, the north pole of the axis points towards the sun, and the observer in the same place as before will now see the sun much nearer the zenith than when the earth was in its midwinter position.

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101. LIGHT AND DARKNESS IN RELATION TO SEASONS.

i. **Explanation of annual variations of day and night.**—(*a*) Place the globe in the position for the spring equinox, and spin it in this position to represent the diurnal rotation of the earth. Notice that every part of the earth is turned towards the light for half of a complete rotation and away from it during the other half.

(*b*) Place the globe in the position for our midsummer day (sun, 23½° north of equator) and spin it. Notice that (1) every place in the northern hemisphere is longer in illumination than in darkness; (2) the north polar regions are not turned away from the light at all during the rotation of the globe; (3) the south polar regions are in darkness throughout the rotation.

(*c*) Place the globe in the position for midwinter day (sun, 23½° south of equator) and notice that (1) places in the northern hemisphere are in darkness longer than in illumination during a spin of the globe; (2) the south polar regions are in illumination during the complete rotation; (3) the north polar regions are in darkness throughout a rotation.

ii. **Graphic representation of duration of sunlight.**—The proportion of sunlight to darkness at different times of the year can be shown graphically by dividing a length into 24 equal parts representing hours, and marking off upon it the number of hours of light and darkness. Upon a piece of chequered paper write the names of the twelve months of the year near the ends of twelve horizontal lines. Number twenty-four vertical lines to represent the hours in a day. The number of hours of daylight in days of different months is shown in the table on p. 385. Upon each horizontal line make a pencil-mark corresponding to the duration of daylight in lat. 52° N. for the month written upon the line. Connect these points and shade the part of the figure representing the hours of darkness. From the diagram thus constructed, the duration of daylight for any time of year in the latitude selected can be determined.

Variation in length of days and nights throughout the year.—Fig. 237 shows the earth in four positions on its orbit, and from what has been said in a preceding paragraph the student will recognise the left- and right-hand positions as those of midwinter and midsummer respectively. We will begin with the first of these, and refer only to the condition of things in the northern hemisphere, reminding the reader that it only

remains for him to exactly reverse this order to know the changes which occur south of the equator. In whatever position the earth may be, one half of it will always be illuminated; and were the axis of the earth perpendicular to the plane of the ecliptic the day and night would always be just twelve hours

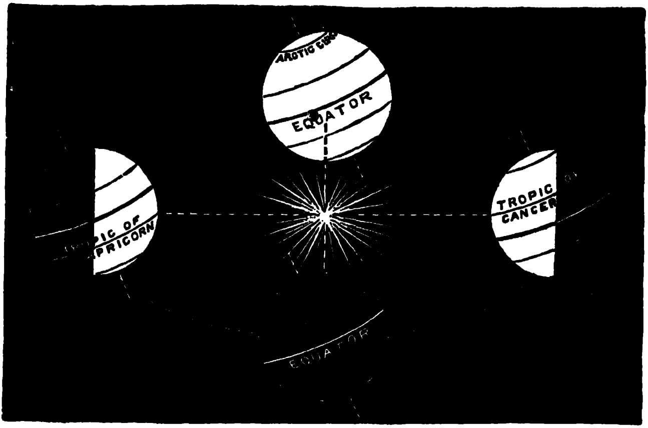

FIG. 237.—The earth in its orbit at the equinoxes and solstices.

long. Supposing the earth in its midwinter position, we must think of it as continually spinning upon its axis, and we will imagine ourselves on some middle parallel of latitude, say, at London. Our latitude, *i.e.* our distance north of the equator, remains the same, and hence during a complete rotation we describe a circle round the earth parallel to the equator. Now, if such a circle be imagined round the earth when it is in this left-hand position, it is quite clear that a much larger part of the circle will be in the dark than will be in the light. This is the same as saying that the observer is in the dark for a much longer time than he is in the light, or for him the nights are longer than the days. In this position the North Pole and places $23\frac{1}{2}°$ from it never come into the light, or places within the circle called the *Arctic circle*, have a continuous night.

When, six months later, the observer has been carried with the earth round to the right-hand position in the figure, the greater part of a circle, representing his path as the earth

rotates, will be in the light, or the days will be longer than the nights. Here places within the Arctic circle never get out of reach of the sun's rays, or for them there is perpetual day.

At the two places on the top and bottom of the figure, midway between the extreme positions described, just one-half of the circle marked out by the observer during a single spin of the earth is in the light, and just one-half in the dark. That is,

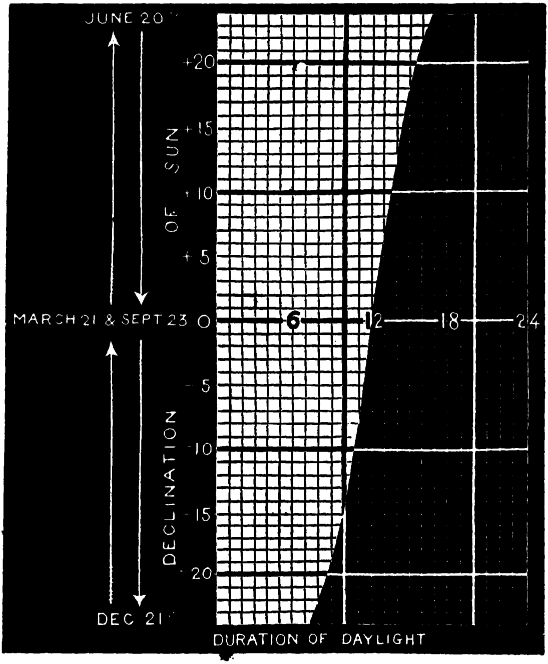

FIG. 238.—Duration of light and darkness in lat. 52° N. corresponding to different declinations of the sun and times of the year.

in these two positions the days and nights are exactly equal in length. These positions are the *equinoxes*, the one passed when the earth is on its way towards midsummer is called the *spring* or *vernal equinox*, and occurs on March 21. The other, when the earth approaches winter, is the *autumnal equinox*, which falls on September 23. This condition of things obtains when

the earth is on the line along which the plane of the equator intersects the plane of the ecliptic.

Duration of daylight in different latitudes.—For every latitude north or south of the equator the lengths of the days and nights vary continually throughout the year. The table given below shows the number of hours of daylight in a day at the beginning of the various months of the year at the equator, in the latitude of part of England, and about the latitude of North Cape. The proportions of daylight to darkness in latitude 71½° N. are also represented in Fig. 238.

Date.	Equator.		Lat. 52° N.		Lat. 70° N.	
	H.	M.	H.	M.	H.	M.
Jan. 1, ...	12	7	7	50	0	0
Feb. 1, ...	12	7	9	8	4	58
March 1, ...	12	7	10	55	9	33
Spring Equinox, . .	12	7	12	11	12	19
April 1, ...	12	7	13	9	14	4
May 1, ...	12	7	14	56	18	55
June 1, ...	12	7	16	23	No night.	
Midsummer Day, . .	12	7	16	44	No night.	
July 1, ...	12	7	16	37	No night.	
Aug. 1, ...	12	7	15	29	21	17
Sept. 1, ...	12	7	13	34	15	30
Autumnal Equinox, .	12	7	12	11	12	19
Oct. 1, ...	12	7	11	3	11	6
Nov. 1, ...	12	7	9	35	6	25
Dec. 1, ...	12	7	8	5	0	0
Midwinter Day, . .	12	7	7	44	0	0

It will be noticed from the above Table that at the equator there are 12 hours 7 mins. of sunlight all through the year. In England the day is only 7 hours 44 mins. long in midwinter, and lengthens from that to 16 hours 44 mins. in midsummer. At the North Cape no sunlight is received for more than two months in winter, and no darkness is experienced for about the same period in summer. These differences are caused by the different manner in which the earth is presented to the sun during its annual revolution with its axis constantly inclined to the ecliptic 23½° out of the vertical.

The midnight sun.—It has been shown that a star at a distance of 51½° from the North Celestial Pole is a circumpolar star at London, that is, its complete diurnal circle is above the horizon at London. Applying the same principle to the sun, it

is evident that if at any time of the year the sun had a Declination of $38\frac{1}{2}°$ N., in which case it would be $51\frac{1}{2}°$ from the North Celestial Pole, the complete diurnal circle would be described above the horizon of an observer in the latitude of London, and the sun would therefore be seen for the whole twenty-four hours. As the sun does not get so far north of the equator as $38\frac{1}{2}°$ N. it is not circumpolar in London at any time of the year. But it does sometimes become circumpolar in latitudes a few

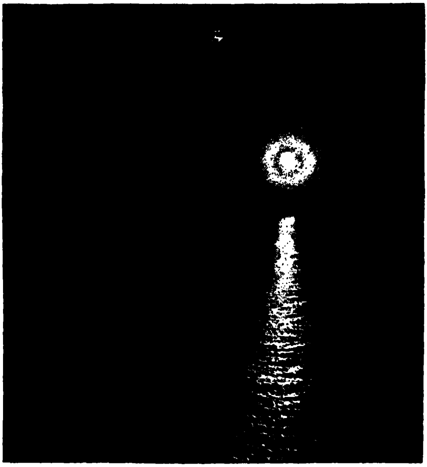

FIG. 239.—The midnight sun. Photographed near Tromsö by Mr D. S. M'Clelland, Aigburth, Liverpool.

degrees further north. As an observer proceeds north from London, the Pole Star gets higher and higher above the horizon, and therefore the circumpolar zone of the celestial sphere becomes larger and larger. In latitude 60° the Pole is 60° above the horizon, and all stars within 60° of the Pole or 30° from the equator describe their complete diurnal paths above the horizon. In latitude $66\frac{1}{2}°$ N., the Pole is $66\frac{1}{2}°$ above the horizon, and therefore all bodies $66\frac{1}{2}°$ from the Pole or $23\frac{1}{2}°$ north of the equator are circumpolar. But the sun is $23\frac{1}{2}°$ N. of the equator on midsummer day; hence its complete diurnal path is above the horizon in latitude $66\frac{1}{2}°$ N. and higher latitudes on that day. At midday it is seen $66\frac{1}{2}°$ south of the Pole and at midnight it is

$66\frac{1}{2}°$ below the Pole, that is, on the northern horizon. This is the phenomena of the midnight sun (Fig. 239).

It is not necessary to describe in any detail the apparent paths of the sun in different latitudes at different times of the year. If the Declination of the sun is known and the latitude of

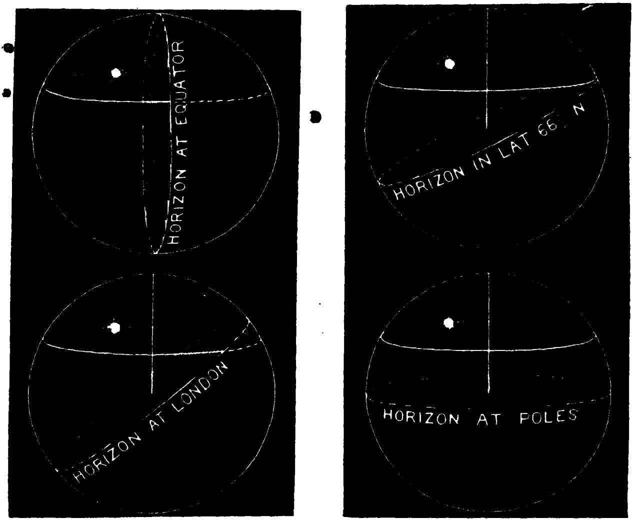

FIG. 240.—The apparent path of the sun on midsummer day, as seen in different latitudes.

the observer, the apparent path can be found by reasoning from the principles already described for stars, or by constructing a diagram similar to that represented in Fig. 240. One or two examples may, however, be helpful.

Example 1. The sun's Declination on April 15 is about 10° N. In what latitude is the sun seen during the whole twenty-four hours?

Declination 10° N. = 80° from North Celestial Pole.

The horizon must therefore be 80° from the Pole.

But altitude of Pole = Latitude.

Therefore, sun is circumpolar in latitude 80° N. or higher.

Example 2. An Arctic explorer saw the sun on the horizon at midnight on May 15. The sun's Declination at the time was 19° N. In what latitude was the observer situated?

Declination 19° N. = 71° from North Celestial Pole.

For the sun to be circumpolar the horizon must therefore be 71° from the Pole.

But altitude of Pole = Latitude.

Therefore, latitude of observer = 71° N.

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102. THE SEASONS.

i. **Explanation of the cause of the seasons.**—Place the globe in the position for midsummer in the northern hemisphere and stick a pin in the position of London. Notice that (1) the light from the lamp, representing the sun, strikes the surface of London nearly vertically; (2) during a rotation the surface is exposed to the rays for a longer period than turned away from it. Place the globe in the position for midwinter day, and notice that the conditions are reversed, the rays now striking the surface at London obliquely, and only shining upon it for a small part of a rotation. Notice also that the midsummer position for the northern hemisphere is the midwinter position for the southern hemisphere, and *vice versa*. The seasonal changes of temperature are due to the annual variations in the length of days and nights (caused by the inclination of the earth's axis) and the different inclinations with which the sun's rays traverse the atmosphere at different times of the year.

The following experiments illustrate seasonal effects:

ii. **Amount of heat received in different periods of time.**—Take two similar thermometers with lamp-black on the surface of the bulbs, and place them side by side opposite a bright lamp. Notice that they show the same temperature when both are screened from the lamp. Expose one for *one* minute and the other for *two* minutes to the rays from the lamp, and notice that the mercury in one rises higher than in the other. Repeat the experiment, but change the two thermometers to which the long and short exposures are given, to show that the difference in the rise of the mercury has nothing to do with the thermometers, and is due to the fact that one is exposed to the heat-source for a longer time than the other. In a similar way, the amount of heat received at a place depends upon the length of time during which the sun's rays are shining upon the place.

iii. **Different action of oblique and vertical rays.**—Take two pieces of sensitive albuminised paper, say one inch square; place them side by side, one with its sensitive surface vertical and the other inclined at an angle to the vertical. Burn two inches of magnesium ribbon, at a distance of a foot from the squares of paper, in such a position that the light falls normally on the vertical piece of paper. This square will be more blackened than the other, showing that light acts more energetically when a surface is at right angles to the direction of the rays. In the same way, when the rays from the sun strike a surface obliquely, they are less powerful than when they strike it vertically or nearly so.

Cause of seasonal changes.—The alternation of the seasons is also the outcome of the inclination of the earth's axis. During the day the earth is continually receiving heat from the sun

which it as regularly radiates into space during the night. Now, *when the days are longer than the nights*, it is evident that more heat is received during the hours of light than is radiated throughout the night, or *there is a net gain of heat.* Whereas, when the opposite holds true, and the nights are longer, there is a *net loss of heat.*

Referring again to Fig. 234, as the earth viewed from above the North Pole moves round its orbit in the opposite direction to the hands of a watch, there is a gradual increase in the lengths of the days and consequently of the net gain of heat, and *the earth gets warmer and warmer* from its midwinter position through the spring equinox towards midsummer; while after the midsummer position has been passed and the earth is moving on through the autumnal equinox towards midwinter again there is a net loss of heat and *the earth becomes gradually colder.*

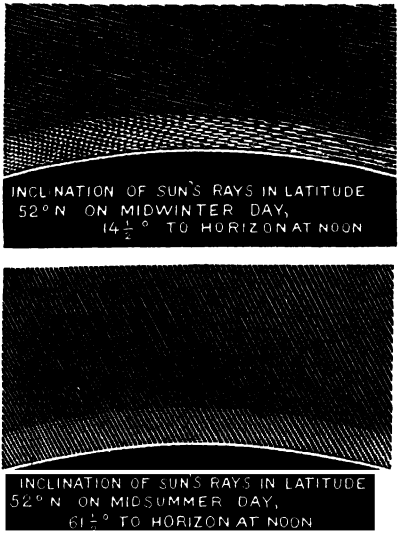

FIG. 241.—Difference of direction in which the sun's rays strike the horizon of a place in lat. 52° N. in midsummer and midwinter.

The varying lengths of the day and night caused by the inclination of the earth's orbit are thus largely responsible for the annual changes of temperature characteristic of the various seasons of the year. Another cause which unites with the varying duration of sunlight to produce seasonal differences is the direction of the sun's rays at different times of the year. In the summer the sun's rays traverse the atmosphere over England almost vertically, so much less of their energy is lost by absorption than is the case in winter when they strike the atmosphere obliquely, owing to the inclination of the northern hemisphere

away from the sun. Moreover, when any bundle of rays strikes a surface vertically their effort is more concentrated than when they strike it obliquely (Fig. 241). The difference of duration, and the difference of inclination, of sunlight cause the variations of temperature of the seasons of the year. At the equator, where the duration of sunlight is constant, and there is little variation in the inclination of the sun's beams, seasons are practically unknown.

CHIEF POINTS OF CHAPTER XXVIII.

The altitude of the celestial equator is equal to 90° minus the latitude of place of observation.

Sun's noonday altitudes at London are:—Equinoxes (March 21 and Sept. 23), 38°; summer solstice (June 20), 61½°; winter solstice (Dec. 21), 14½°.

Variation of points of sunrise and sunset.—In the latitude of London the points of sunrise vary from 40° N. of. E. to 40° S. of E., and the points of sunset vary from 40° N. of W. to 40° S. of W.

The midnight sun is seen when the angular distance of the sun from the North Celestial Pole is less than the latitude of the place.

The inclination of the earth's equator to the plane of the ecliptic is 23½°. On account of this and the earth's revolution we get: (1) The noonday altitude of the sun changing throughout the year; (2) an annual variation in the positions at which the sun rises and sets; (3) days and nights of unequal length; (4) the succession of the seasons.

The annual changes of temperature are caused (1) by the unequal lengths of days and nights; (2) by the sun's rays passing through the earth's atmosphere and striking the surface at different angles.

EXERCISES ON CHAPTER XXVIII.

1. Why are the days longer in summer than in winter? Explain the difference noted at these seasons:
   (*a*) In the sun's declination.
   (*b*) In the places of sunrise and sunset.

2. Give an account of the apparent movements of the stars depending upon:
   (*a*) The earth's revolution on its axis.
   (*b*) The earth's rotation round the sun.

3. What difference is observed in the place of the rising and setting of the sun (1) at different times of the year at any place in the British Isles; (2) at the summer solstice in different parts of the northern hemisphere?

4. At about what time of year were the following lines spoken, referring to the rising of the sun at Rome?

> "Here as I point my sword, the sun arises,
> Which is a great way growing on the south,
> Weighing the youthful season of the year.
> Some two months hence up higher towards the north
> He first presents his fire."—*Julius Cæsar*, Act II., Sc. i.

5. Give a diagram explaining the difference in the sun's latitude at noon in England on the longest and shortest days of the year.

6. Can the sun ever be directly overhead in any part of England? Give reasons for your answer.

7. What is the difference between the altitude of the sun at noon on midsummer day and on midwinter day?

8. In what latitude is the sun in the zenith at noon (*a*) on midsummer day, (*b*) at the equinoxes, (*c*) on midwinter day?

9. The Tropics of Cancer and Capricorn are circles 23½° north and south of the equator. Why should they be situated in these latitudes more than in any other?

10. Describe an experiment to explain the variations in the lengths of the day and night in England during the year. On midsummer day are the days longer or shorter in the north than in the south of England?

11. Draw a diagram showing the positions of the earth and its axis with reference to the sun at the summer and winter solstices, and the direction of the zenith of London at noon on each of these days.

12. What causes produce the seasonal changes of temperature in England in the course of the year?

13. Explain by a diagram why the days in Great Britain are longest in June and shortest in December?

14. What difference could you observe:

(*a*) Between the position of the sun when it is rising in December and when it is rising in June?

(*b*) Between its position at noon in December and its position at noon in June?

15. Explain why in the zone on the earth between lat. 23½° N. and lat. 23½° S. the sun appears vertical in the sky twice in a year.

16. What are the principal motions of the earth. Explain how it is that varying seasons, and days and nights of unequal duration, are caused by the plane of the equator being inclined to the plane of the ecliptic.

17. How could a globe be used to explain the varying length of day and night according to the season of the year and the different times of day at places in the same latitude?

18. Explain, with diagrams, why the days are (*a*) longer, (*b*) warmer in summer than in winter.

19. Explain and illustrate by a diagram (*a*) the succession of the four seasons, (*b*) the variation in the length of day and night during the year.

20. Account for the different heights of the sun above the horizon at noon throughout the year.

21. The sun's declination of Aug. 1 is 17° 50′ N. To what latitude would a traveller have to go in order to see the "midnight sun" on that date?

CHAPTER XXIX.

THE MOON AND ECLIPSES.

103. APPARENT VARIATIONS IN SHAPE OF THE MOON.

i. **Phases of the moon.**—Find the time of New Moon from a calendar. Observe the moon about the time of sunset two or three nights later; and when you think it is Half Moon reckon the number of days that have elapsed since New Moon. In a similar way, find the number of days from Half Moon to Full Moon, from Full Moon to Last Quarter, and from Last Quarter to New Moon. The shape of the moon should be drawn from week to week in connection with these observations.

ii. **New moon and crescent moon.**—Look up the time of New Moon in a calendar. Look for the crescent moon above the sun at sunset two or three days later. Find, by making the observation several months, the shortest interval between the time of New Moon as given in the calendar and that at which you first catch sight of the crescent moon. Notice that the horns of the crescent moon are always directed away from the sun.

iii. **Explanation of phases of the moon and related phenomena.**—(*a*) Place a lighted lamp upon a table, and a globe at a short distance from it; these represent respectively the sun and earth. Obtain a small white ball—about one-quarter the diameter of the globe—to represent the moon. Carry the ball around the globe as indicated in Fig. 242, and notice that though a hemisphere of the ball is always illuminated, the amount of illuminated surface visible from the globe depends upon the relative positions of the lamp, globe, and ball. Show in this way the relative positions of the three bodies, at the times of (1) New Moon, (2) Half Moon, (3) Full Moon, (4) Half Moon again.

(*b*) Notice that when the ball is between the globe and lamp only the dark side is turned towards the globe. This represents the condition for the astronomical New Moon. Move the ball a little in the direction indicated, and a crescent of light can be seen from the globe, just as the crescent moon becomes visible a few days after New Moon.

iv. **Length of a lunation.**—(*a*) Find, by means of a calendar, the dates of the next four New or Full Moons from the present time. Calculate the number of days, hours, and minutes between each New or Full Moon and the next. If one of the dates involved in this calculation is a.m. and the other p.m., remember to take this into consideration in determining the length of the lunation.

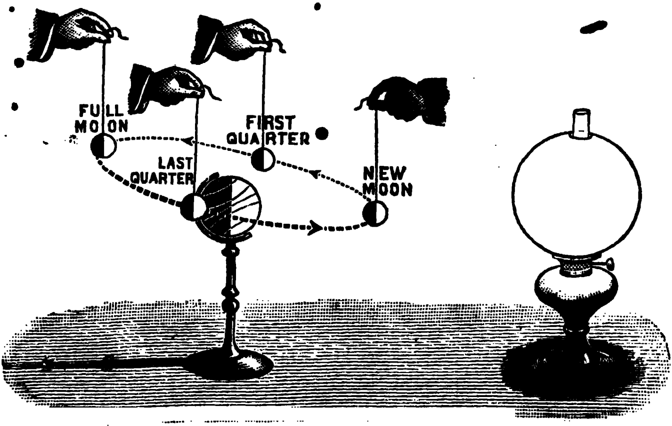

FIG. 242.—Experiment to illustrate the cause of phases of the moon.

(*b*) Verify by actual observation the dates of Full Moon given in the calendar; or, better, determine the time of Full Moon by observation, and verify it by reference to a calendar.

Phases of the moon.—The continual variations in the extent and shape of the illuminated part of the moon are known as the phases of the moon. From New Moon to New Moon again

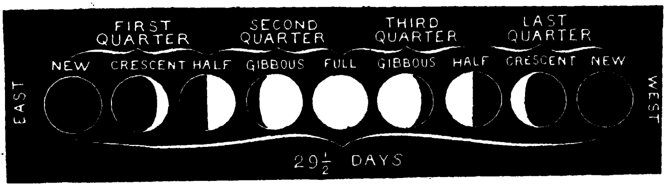

FIG. 243.—Phases of the moon, and length of a lunation.

these phases follow a sequence which is the same month after month and has been remarked by everyone. Starting from New Moon, the series of changes can be divided into four

Quarters—each about a week in length. The Quarters are—First—New Moon to Half Moon; second—Half Moon to Full Moon; third—Full Moon to Half Moon; fourth—Half Moon to New Moon. The exact number of days, hours, and minutes in each of these Quarters, and the length of the complete interval from one New Moon to the next can be found by reference to a calendar. The following dates, for instance, have been obtained in this way:

		Dates of Quarters. D.	H.	M.		Lengths of Quarters. D.	H.	M.
First Quarter,	New Moon, -	April, 13	4	23	A.M.	7	18	24
Second Quarter,	Half Moon, -	April, 20	10	47	P.M.	6	15	0
Third Quarter,	Full Moon, -	April, 27	1	47	P.M.	7	1	38
Last Quarter,	Half Moon, -	May, 4	3	25	P.M.	8	4	21
	New Moon, -	May, 12	7	46	P.M.			
Total Length of Lunation, or Lunar Month, -						**29**	**15**	**23**

Several facts are brought out by a table of this kind. In the first place it will be noticed that New Moon, Full Moon, and other phases occur at various hours of the day—sometimes in the morning and sometimes in the afternoon. Next, the intervals between New Moon and Half Moon, Half Moon and Full Moon and so on, that is, the lengths of the lunar Quarters, are not exactly the same, but are, roughly, a week in duration. Thirdly, the total length of time from one New Moon to the next is, in the case given, a little more than 29½ days. This length varies somewhat, as will be seen from the following table showing the times of four successive New Moons and four successive Full Moons in 1900.

New Moons.	D.	H. M.	D.	H.	M.	Full Moons.	D.	H. M.	D.	H.	M.
May,	28	2 50 P.M.	29	10	17	June,	13	3 39 A.M.	29	9	43
June,	27	1 27 A.M.	29	11	16	July,	12	1 22 P.M.	29	8	8
July,	26	1 43 P.M.	29	14	10	Aug.,	10	9 30 P.M.	29	7	36
Aug.,	25	3 53 A.M.				Sept.,	9	5 6 A.M.			

The average length of a *lunar month*, that is, of the interval between two successive Full Moons or New Moons, is 29½ days.

The occurrence of phases of the moon can easily be explained. The moon travels round the earth once a month in much the same way that the earth travels round the sun once a year. The moon has no light of its own, but that of the sun is continually shining upon its surface, hence the light which it appears to possess is really reflected sunlight. We do not, however,

always see the illuminated half of our satellite, and the consequence is that we get the phases or changes of the moon familiar to every one who has sight.

The moon is shown in several positions in its path in Fig. 244. In every position sunlight is illuminating a complete hemisphere, but it will be seen that the form and extent of the visible illumination depends upon the relative positions of the earth and moon. At New Moon the illuminated hemisphere is turned away from the earth, so nothing is seen of our

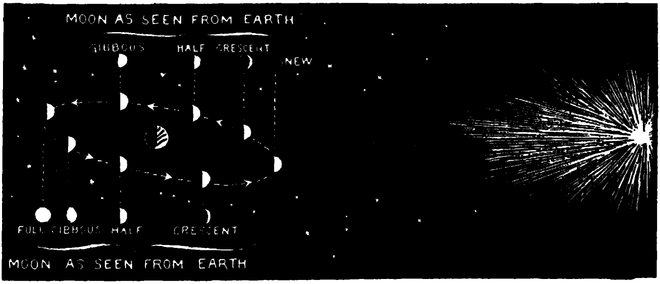

FIG. 244.—The moon in its orbit, showing how lunar phases are caused.

satellite. As the moon travels in the direction indicated, first a crescent of light is seen, then the Half Moon, then the gibbous phase, and afterwards Full Moon, at which time the whole of the illuminated hemisphere is seen, the moon being directly opposite the sun. From Full Moon to New Moon again it will be noticed that the changes occur in the reverse order.

As the moon derives its light from the sun, the illuminated part of its surface must always face the sun. This explains why the crescent moon seen in the evening always has its horns pointed away from the sun, that is, towards the east, while in the crescent moon which rises shortly before the sun, the horns are pointed towards the west. The illustration of the causes of the phases of the moon (Fig. 244) will enable the student to understand the reason of this difference.

104. ROTATION OF THE MOON. EARTH-SHINE.

i. Rotation of the moon.—Push a knitting needle horizontally through the ball used in Experiment 103 i. Make a blotch

of ink upon the ball to represent a marking upon the lunar surface. Carry the ball round the globe in the same way as was done in illustrating the phases of the moon. It will be seen that in order to keep the blotch of ink facing the globe the knitting needle must turn completely round while the ball through which it is stuck performs its journey. If the needle is kept constantly pointing in one direction, all parts of the ball are turned in succession towards the globe.

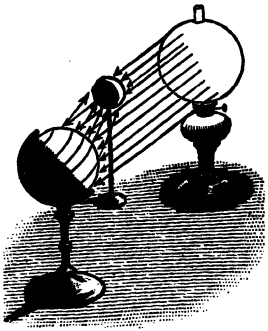

FIG. 245.—To explain earth-shine.

ii. **Earth-shine and its cause.**—(*a*) Look for the crescent moon as early as possible after New Moon. The dark body of the moon can usually be seen embraced by the crescent of light on one side. The appearance can always be seen with a small telescope.

(*b*) Place a lamp, ball, and globe in the relative positions for illustrating the production of a crescent moon a few days after New Moon (Fig. 245). Notice that the globe as well as the ball is illuminated, and that the reflection of the light from the globe causes the hemisphere of the ball facing the globe to be faintly visible. The moon receives *earth-shine*, or sunlight reflected from the earth, in the same way a few days before and after New Moon, and this produces the phenomenon observed.

The moon rotates on its axis once a month.—The "man in the moon" always appears to have the same expression; in other words, the same face of the lunar surface is always seen by us. This is because the moon rotates on an axis in the same time that it revolves around the earth. When, for instance, the moon has travelled over a quarter of a revolution it turns on its axis by a quarter of a rotation, and so prevents us from seeing the new lunar scenery which would, but for this compensating cause, become visible.

If the moon did not rotate on its axis, we should be able to see all parts of it in the course of a revolution around the earth, whereas a large part of the lunar globe is never seen.

Earth-shine.—A few days after New Moon it is often possible to see the moon as a globe having a crescent of illumination on the side facing the sun. This phenomenon is known as the "old moon in the young moon's arms," and a photograph of it is shown in Fig. 246. The explanation of the appearance is comparatively simple. The sun illuminates the

earth as well as the moon, and the earth reflects part of the light thus received. This reflected light striking the moon faintly illuminates the hemisphere of the moon turned to the earth and causes that hemisphere to be dimly seen. The hemisphere is thus seen by second-hand sunlight, or, as it is termed, *Earth-Shine.* It will be noticed that the bright crescent moon appears to be part of a larger body than the dark portion. This is, of course, not actually the case, the effect being due to what is known as *irradiation*, on account of which a bright object appears larger than a dark one to the eye, and its image tends to spread out on a photographic plate.

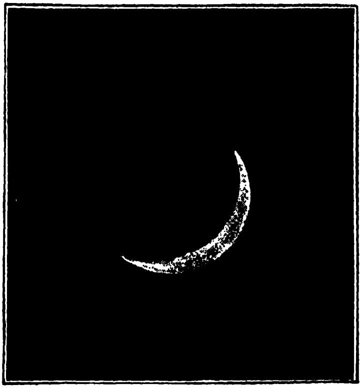

FIG. 246.—The old moon in the young moon's arms. From a photograph by Prof. E. E. Barnard. (*Monthly Notices of the Royal Astronomical Society.*)

105. THE MOON'S MONTHLY PATH.

i. **Eastward motion of the moon.**—Notice the position of the moon on any night. Repeat the observation several nights at the same hour. Observe that every night the moon is further east at the same hour than it was the night before. Notice that, on account of this, the position of the moon with reference to the stars continually changes.

ii. **Determination of moon's path among the stars.**—From *Whitaker's Almanack*, or a similar publication, find a date when the moon's Right Ascension at noon is almost zero. Using squared paper as in Fig. 247, make a mark at the proper Right Ascension and the corresponding Declination of the moon on the date found. Locate similar points upon the squared paper to show the Right Ascension and Declination of the moon on alternate days at noon as given in the Almanack, until the XXIVth hour of Right Ascension is reached. Connect the points thus determined; the line obtained shows the path of the moon on the celestial sphere in the month selected.

iii. **Interval between successive southings of the moon.**—(*a*) Fix a simple theodolite or pointer so that a sight can be taken due south. Observe the times at which the moon appears due south on several nights in succession. The time of transit will be found to be about

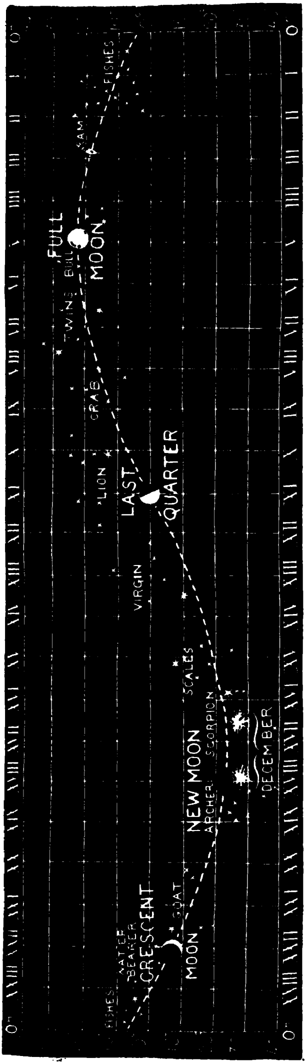

FIG. 247.—Path of the moon among the stars in December 1900, with corresponding phases. The sun's positions during the same month are indicated.

50 minutes later every night. The times of rising and setting are correspondingly belated.

(*b*) Test this statement by means of the times of rising or setting of the moon given in a calendar.

iv. **Explanation of eastward motion of moon.**—Place the lamp, ball, and globe upon the table as in Experiment 103. Imagine objects and marks upon the walls, floor, and ceiling of the room to represent stars. Carry the ball around the globe to represent the monthly revolution of the moon around the earth. An observer imagined upon the globe would see the ball projected upon different objects during the revolution of the ball in its orbit. In a similar way, the moon is seen projected upon different parts of the celestial sphere on account of its movement around the earth. Unlike the eastward motion of the sun, which is only an *apparent* motion due to the real movement of the earth, the eastward motion of the moon is a *real* motion due to the actual revolution of the earth's satellite.

Moon's motion among the stars.—If the stars could be seen with the sun during the day throughout a whole year, the position of the line of travel—the ecliptic—could be easily and accurately determined. But though this cannot conveniently be done in the case of the sun, the observation is easy in the case of the moon—"the lesser light made to rule the night."

We see the moon at the same time as the stars, and associated with it, and the most casual observer has learned that it moves among them. To-night it appears to be near certain stars; to-morrow it is to the east of this position, the next day farther east, and in twenty-seven days eight hours it has travelled eastwards completely round the sky.

In all probability, the apparent path of the moon was known before that of the sun had been indirectly observed. Be this as it may, when the two paths had been determined they would be found to follow very nearly the same course around the sky. In other words, the sun in its annual journey and the moon in its monthly journey keep in very nearly the same track.

Determination of moon's path on the celestial sphere.—By determining the Right Ascension and Declination of the moon day after day, the path of the moon among the stars can be found in the same way as with the sun, and can be shown graphically upon a chart as in Fig. 247. The following table shows the Right Ascension and Declination of the moon at noon for alternate days from the beginning of December, 1900, when the moon was close to the starting point of Right Ascension, to December 28, 1900, when it had made the complete circuit of the heavens.

Date.		Right Ascension at Noon.		Declination at Noon.		
		H.	M.			
December	1	0	0	5°	3′	N.
,,	2	0	55	10	0	N.
,,	4	2	52	17	59	N.
,,	6	4	54	21	24	N.
,,	8	6	53	19	25	N.
,,	10	8	41	13	19	N.
,,	12	10	16	5	7	N.
,,	14	11	46	3	34	S.
,,	16	13	15	11	38	S.
,,	18	14	51	17	57	S.
,,	20	16	36	21	14	S.
,,	22	18	27	20	20	S.
,,	24	20	17	15	1	S.
,,	26	22	4	6	22	S.
,,	28	23	48	3	45	N.

When these two coordinates are plotted for the various dates, a line connecting them represents the path of the moon upon

the celestial sphere in the month selected. The path thus determined (Fig. 247) proves to be very similar to the apparent annual path of the sun. The time occupied in making the complete circuit of the heavens was from noon on December 1 to a little after noon on December 28, that is, a little more than 27 days. This (or more exactly, 27⅓ days) is the length of a *sidereal month*, and it is determined, as here explained, by observing the interval between two successive appearances of the moon on the same celestial meridian.

106. MONTHLY CHANGES OF THE MOON'S POSITION WITH REFERENCE TO THE SUN.

i. **Relative positions of sun and moon.**—Notice the relative positions of the sun and moon two or three days after the time of New Moon given in a calendar. Make a rough measure of the angular distance between the two bodies. Repeat the observation at the same hour as many nights as possible, and determine from the measures the daily increase of angular distance; it will be found to be about 13°.

ii. **Explanation of relative times of rising and setting of sun and moon.**—Place the lamp, ball, and globe in the position to represent the cause of New Moon (Fig. 242). Rotate the globe slowly on its axis. Notice that the sun (lamp) and moon (ball) would appear on the meridian of any place, that is, due south at the same time. Move the ball for a short distance in the direction indicated, and again rotate the globe; the sun now rises, souths, and sets a little before the moon. Move the ball to the first Half Moon position, and rotate the globe; there is now a difference of one quarter of a rotation, that is, six hours, between the times of rising, southing, and setting of the sun and moon. Place the ball in the Full Moon position; the moon now rises, and is due south at midnight, and sets twelve hours after the sun. From this point to the New Moon position the difference between the times of rising, southing, and setting of the sun and moon decreases. At the beginning of the Last Quarter the moon rises, souths, and sets six hours before the sun, and this gets less and less until the sun and moon are again upon the same celestial meridian, and therefore rise, south, and set together.

Relative positions of sun and moon during a lunation.—It has already been sufficiently explained that the rising, southing, and setting of celestial objects are due to the rotation of the earth, and the times at which they occur depend, therefore, upon the positions of the objects upon the celestial sphere. Two bodies upon the same celestial meridian rise, south and set at the same time; if they are separated by 90°, one rises,

souths, and sets about six hours before the other; if they are separated by 180°, the difference in the times is twelve hours, and so on, proportionally, for other intervals.

At New Moon, the sun and moon are on the same celestial meridian, or are in *conjunction*, to use the correct astronomical word; they therefore rise, south, and set together. About seven days later, the moon rises, souths, and sets six hours after the sun, no matter what the time of year. A little more than seven days more, at Full Moon, the moon is twelve hours behind the sun, and therefore is due south at midnight, in which position the moon is said to be in *opposition*. After this the moon does not appear due south until the early morning hours; it gets

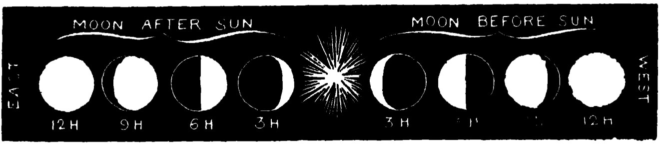

FIG. 248.—Relative positions of sun and moon at different lunar phases.

later and later every day until it again souths at the same time as the sun, namely, at the time of New Moon. The times of rising, southing, and setting of the moon at the chief phases of a particular lunation are shown in the following table:

		Moon.			Sun.	
		Rises.	Souths.	Sets.	Rises.	Sets.
	D. H. M.	H. M.	H. M.	H. M.	H. M.	H. M.
New Moon, Nov.	22 7 17 A.M.	**7 39** A.M.	11 55 A.M.	**4 7** P.M.	**7 31**	**4 1**
First Quar., ,,	29 5 35 P.M.	Noon.	5 56 P.M.	11 53 P.M.	7 42	3 54
Full Moon, Dec.	6 10 38 A.M.	4 9 P.M.	Midnight.	7 40 A.M.	7 51	3 51
Last Quar., ,,	13 10 42 P.M.	Midnight.	5 23 A.M.	11 36 A.M.	7 59	3 49
New Moon, ,,	22 0 1 A.M.	**8 11** A.M.	Noon.	**4 43** P.M.	**8 6**	**3 52**

As the sun souths at 12 noon every day, it is not necessary to give a column to show its time of southing.

The numbers in this table exemplify the statements already made as to the times of rising, southing, and setting of the moon and sun during a lunation. The fact that the sun and

moon are in the same part of the sky at the time of New Moon is clearly shown on Nov. 22. When the moon rises only two or three hours after the sun, a few days after New Moon, it cannot be seen to rise because of the overpowering brightness of sunlight. But towards sunset this bright glare is diminished, and the crescent moon is seen above the sun in the western sky. This is what people call the New Moon, though really the New Moon occurred two or three days before. If the earth had no atmosphere, the crescent moon would be seen immediately it appeared above the eastern horizon, and would be visible a little to the east of the sun throughout the day After the commencement of the last quarter, there is another

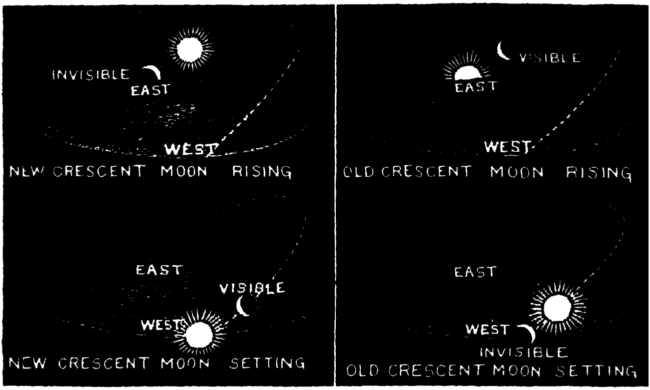

FIG. 249.—Relative positions of the sun and moon at the times of rising and setting of new and old crescent moons.

crescent moon which rises shortly *before* the sun in the early morning hours, and is overpowered by atmospheric glare when the sun appears above the horizon (Fig. 249). From these facts it will be understood that a rising crescent moon could never be seen in the evening, nor a setting crescent moon in the morning. Artists who introduce such objects into their pictures, and novelists who describe them, are untrue to nature.

Position of sun and moon in the celestial sphere.—Knowing the position of the sun upon the celestial sphere at any time, and also the position of the moon, it is easy to determine their relative times of rising, southing, and setting. For

instance, in the month of December the sun occupies points on the celestial sphere between the hours XVI. and XVIII. of Right Ascension. The path of the moon during this month is shown in Fig. 247, and also the positions of the sun in December. The Full Moon is seen to be twelve hours distant from the sun, and the New Moon is seen to be a little north of the position the sun occupied on December 22. The relative positions of the sun and moon can be shown graphically in this way upon any date, when the Right Ascensions and Declinations of the two bodies are known, and the diagram thus constructed make it possible to determine by a glance the relative times of rising, southing, and setting of the two bodies.

As the moon when full is at the opposite point of the celestial sphere from that occupied by the sun, it follows that when the sun is north of the celestial equator the Full Moons are south, and when the sun is south of the celestial equator the Full Moons are north of it. The sun is south of the equator in the winter months, hence at this time of year the moon, being north of it from the First to the Last Quarter (see Fig. 247), is longer above the horizon than in summer; for a large part of its diurnal path is presented to us. Expressed in another way, when the sun's path above the horizon is large the moon's is small; and at the season when the sun is only a short time above the horizon, the moon is a long time above it.

107. HARVEST AND HUNTER'S MOONS.

Daily retardation of the moon.—Find from a calendar the times of rising of the moon from September 22 to September 30. Determine, by subtraction, the amount of time by which the moon rises later day by day. Make the same determination for corresponding days in another month. Notice that the daily retardation is greater than in September.

Daily difference in times of rising.—Though on the average the moon rises, souths, and sets 51 minutes later every day, this daily retardation varies very considerably. An examination of the times of rising given in a calendar will show, for instance, that the moon rises about thirty or forty minutes later day by day near the time of the autumnal equinox, whereas the difference between the times of rising on two successive days is usually greater in other months. The following table exemplifies this;

Date.	Retardation of Moon.	Date.	Retardation of Moon.
	H. M.		H. M.
Sept. 22-23	0 37	Nov. 22-23	0 33
„ 23-24	0 32	„ 23-24	0 38
„ 24-25	0 32	„ 24-25	0 45
„ 25-26	0 29	„ 25-26	0 55
„ 26-27	0 28	„ 26-27	1 3
„ 27-28	0 30	„ 27-28	1 9
„ 28-29	0 33	„ 28-29	1 12
„ 29-30	0 38	„ 29-30	1 12

Harvest and Hunter's moons.—The Full Moon that occurs nearest the autumnal equinox (September 22) is called the Harvest Moon, and the next Full Moon is known as the Hunter's Moon. It is easy to find, by observation or reference to a calendar, that at the times of Harvest and Hunter's Moons the moon rises at nearly the same time for several nights in succession, and the long moonlight nights thus produced attract attention. When Full Moon happens to occur within a few days of September 22 and only gets later by about half an hour night after night, it seems as if the moon is full (or nearly so) for a much longer period than usual. If, however, New Moon happens to occur about this date, the fact that it rises at nearly the same hour for several nights is not particularly noticed.

If the moon moved uniformly around the celestial equator every month, it would always rise and set east and west, and the times of rising, southing, and setting would get later by the same amount every day. But the moon moves nearly along the ecliptic, which is inclined to the equator, and it is for this reason that the daily retardation differs. The daily differences are least at the autumnal equinox, when the ecliptic is least inclined to the horizon; hence the Full Moons which occur at this time of year are visible for longer periods than usual.

108. LUNAR ECLIPSES.

i. Eclipses of the moon.—(*a*) Find from a calendar the dates of three eclipses of the moon, past or future. Find also the dates of the three full moons in the same month. Notice that the dates are the same, thus showing that eclipses of the moon happen at Full Moon. This is true whether the eclipse is total or partial.

(*b*) To determine whether the eclipses could be observed in Eng-

land, look up the times of the moon's rising and setting on the dates on which they occur. If an eclipse happen between these times, it will be visible if the sky is clear; but should an eclipse happen at a time when the moon is below the horizon of a place, it would, of course, be invisible from that place.

ii. **Explanation of eclipses of the moon.**—Place a globe, representing the earth, near a lighted lamp representing the sun. Notice that a shadow of the globe is thrown by the lamp and can be caught upon a screen. Fix a small ball upon a stand and bring it gradually into the shadow until the centres of the lamp, globe, and ball are in a straight line, and the ball is completely immersed in the shadow (Fig. 250). This illustrates how an eclipse of the moon is caused by the moon passing into the shadow of the earth. Notice that the ball is in the position for Full Moon when the eclipse occurs. By raising or lowering the ball so as to be only partially in the dark central shadow, the conditions for a partial eclipse of the moon can be illustrated.

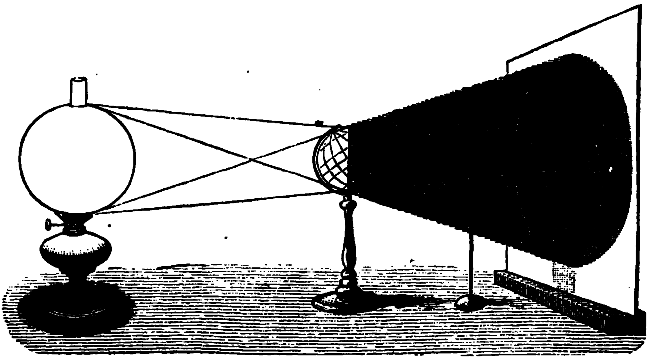

FIG. 250.—Illustration of the cause of an eclipse of the moon.

Cause and character of eclipses of the moon.—In the subjoined table the dates of three eclipses of the moon, and of three Full Moons, are given in Greenwich time. The distance of the moon from the ecliptic upon each of the dates is also tabulated:

Date of Eclipse.				Date of Full Moon.			Character of Eclipse.	Angular distance of Moon from Ecliptic.
		D.	H.		D.	H.		
1901.	Oct.	27	3	Oct.	27	3	Partial.	1° 4′
1902.	Apr.	22	7	Apr.	22	7	Total.	0° 15′
,,	Oct.	16	18	Oct.	16	18	Total.	0° 14′

An important fact brought out by this table is that all the eclipses occur at the times of Full Moon. Another point worthy of notice is that, when a partial eclipse of the moon happens, the moon is further from the ecliptic than when a total eclipse occurs. These facts can be easily explained. The sun is always shining upon the earth, and the earth's shadow is always pointed directly away from the sun. When a large light shines upon a small globe the dark shadow has the form of a cone, the apex of which lies in the same line as the centres of the two objects, hence the apex of the shadow of the earth lies in the same plane as the centres of the sun and earth, that is, in the ecliptic. In addition to the dark shadow (the *umbra*) a fainter shadow, known as the *penumbra*, is produced when a luminous body shines upon a smaller non-luminous one. (See Expt. 108, ii.)

Now, as the moon revolves around the earth nearly in the plane of the ecliptic, and as it is not far enough away to be beyond the apex of the earth's shadow, it must occasionally pass into the shadow. When this happens—and as the shadow is pointed away directly from the sun it can evidently only occur

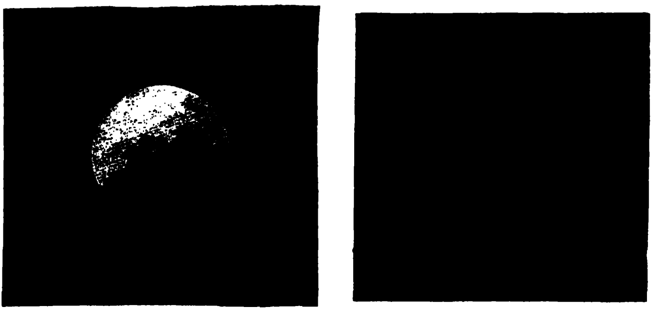

FIG. 251.—Partial and total eclipses of the moon.

at Full Moon—the moon is eclipsed. The moon first travels into the penumbra and is still visible though its brightness is diminished. When the umbra is reached, however, the part of the moon within it becomes almost invisible, and it is at this stage we have the appearance represented in Fig. 251, where the circular outline of the earth's shadow is seen. Even after the moon has passed entirely into the umbra, a dull red disc can

still be made out. This is because sunlight is refracted by the earth's atmosphere and so made to strike upon the moon's surface, which reflects it to us. The coppery colour is due to the passage of these rays through the earth's atmosphere.

So far as we have proceeded at present there is apparently no reason why a lunar eclipse should not happen at every Full Moon. If the plane in which the moon revolves round the earth were coincident with that in which the earth travels round the sun, there would be an eclipse at each Full Moon. But the moon's orbit is inclined to the plane of the ecliptic, and it therefore happens that usually at Full Moon the earth's satellite is above or below the shadow cast by the earth and no eclipse occurs (Fig. 252). At other times the moon partially passes

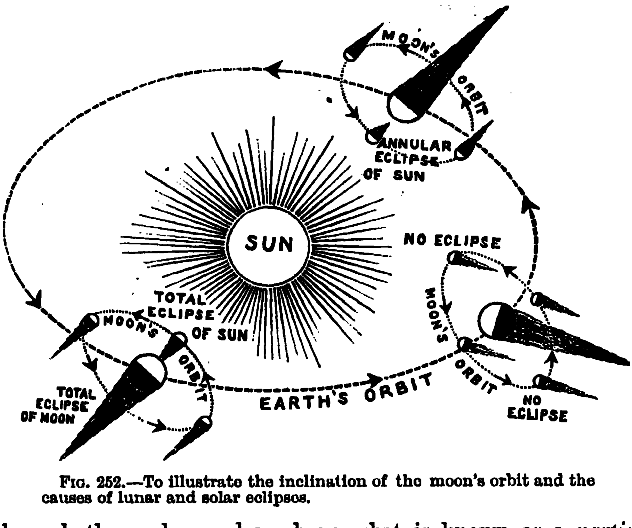

FIG. 252.—To illustrate the inclination of the moon's orbit and the causes of lunar and solar eclipses.

through the umbra and we have what is known as a *partial eclipse*. It is only when the centres of the sun, earth, and moon are nearly in the same line at the time of Full Moon that a total eclipse of the moon can occur.

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109. SOLAR ECLIPSES.

i. Eclipses of the sun.—Find from a calendar the dates of three eclipses of the sun, past or future. Find also the dates of the three

New Moons. Notice that the dates are the same, thus showing that eclipses of the sun happen at the times of New Moon. Observe that three kinds of solar eclipses are specified, viz., (1) total eclipse, (2) partial eclipse, (3) annular eclipse. Each of these kinds may be visible or invisible in England.

ii. **Explanation of eclipses of the sun.**—(*a*) Place a lighted lamp and a globe a short distance apart, and a small ball between them. Let the ball be at such a distance that its shadow only appears as a small spot on the globe (Fig. 253). From any point within this spot the lamp could not be seen. The conditions of an eclipse of the sun are therefore illustrated by this arrangement. Notice that the ball is in the position for New Moon.

(*b*) Rotate the globe a little on its axis; several parts are thus brought within the spot, as in the track of a solar eclipse. The eclipse can only be seen from a point within this strip; in other parts no eclipse is observable even though the sun is visible. From points a little above or below the eclipse-track the sun is seen partially eclipsed.

(*c*) Arrange the lamp, ball, and globe so that the shadow of the ball does not quite reach the surface of the globe. From a point just under the apex of the cone of shadow, the ball would not completely obscure the light, and a ring or annulus of luminosity would be seen. This illustrates the conditions of an annular eclipse.

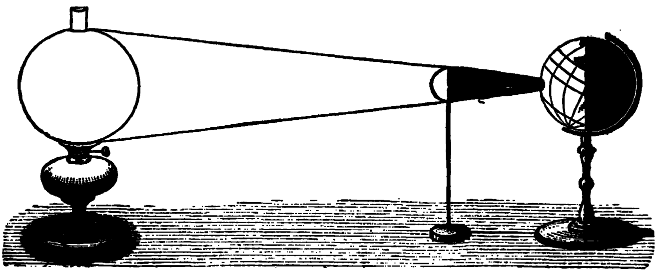


FIG. 253.—Experiment to explain how an eclipse of the sun is caused.

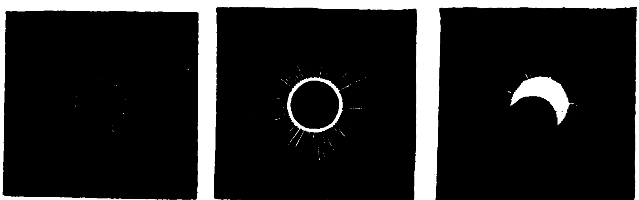
Cause and character of solar eclipses.—The dates and characteristics of four eclipses of the sun are given below, together with the times of New Moon.

Date of Eclipse.	Date of New Moon.	Character of Eclipse.	Angular distance of Moon from Ecliptic.
D. H.	D. H.		
1901. May 17 17	May 17 17	Total	0° 23′
,, Nov. 10 19	Nov. 10 19	Annular	0° 27′
1902. Apl. 8 3	Apl. 8 2	Partial	1° 34′
,, May 7 10	May 7 10	Partial	1° 7′

A comparison of these columns indicates some interesting facts. The eclipses are seen to occur on the day of New Moon, and this is true for every eclipse of the sun. At the time of total eclipse the moon is very near the ecliptic, and at the time of a partial eclipse it is farther from the ecliptic than when a total eclipse occurs. An additional examination of the information given in a good calendar would also show that an annular eclipse occurs when the moon is close to its furthest point from the earth.

An eclipse of the sun is caused by the moon coming between the sun and the earth, and so obscuring our source of light. Or, expressed less accurately, the sun casts a shadow of the much smaller moon, and the shadow sometimes falls upon the earth. But the shadow only extends over a small part of the earth's surface, hence an eclipse of the sun is not visible everywhere upon the earth, but only at certain places where the moon is in the way between the observer and the sun.

In its movement around the earth the moon is sometimes nearer the earth than at others. *Total* solar eclipses, when the sun is quite blotted out by the moon, occur when the moon is near its nearest point to the earth, and also close to the ecliptic at the same time. If the moon is near its most remote point, and close to the ecliptic at the same time, the shadow cast by the moon falls short of the earth, and consequently the appearance to an observer in the line of the shadow is different. The moon then cuts off all the light of the sun excepting a ring of light surrounding the circle of darkness, and we have what is called an *annular eclipse* (Fig. 254, B).



A B C

FIG. 254.—Total (A), annular (B), and partial (C) eclipses of the sun. The photograph of the total eclipse shows the solar corona.

An annular eclipse of the *moon* cannot occur, because, whether the moon is at its nearest or farthest points, the earth's shadow

at the point where the moon crosses it has a much greater diameter than the diameter of the moon. Sometimes the moon does not pass in a direct line between the sun and the earth at New Moon, but is slightly above or below the ecliptic. Under these conditions the sun is only partially covered. So a partial eclipse occurs (Fig. 254, C).

The phenomena observed during a total solar eclipse are very striking. The moon's disc first appears on the western edge of the sun, and gradually covers up the whole surface. When the sun is thus totally obscured there is very little light, and the bright stars can be seen as at the beginning of night. Around the sun and extending in luminous sheets and streamers for thousands of miles is seen the *solar corona* (Fig. 254, A). In addition to this halo, a number of red-coloured "prominences" or solar flames may be seen shooting out from the sun behind the dark edge of the moon.

110. THE MOON'S SURFACE STRUCTURE.

i. Observations of the moon's surface.—(*a*) Using a small telescope or field-glass, observe the moon when it is only a few days old. Notice that the whole of the disc can be dimly seen. The edge of the bright part of the disc facing the sun is sharply defined, but the line—called the terminator—separating the illuminated portion of the disc from the dark portion is irregular in outline, owing to the fact that the moon's surface receiving the sunlight is rugged. If the surface were perfectly smooth, the terminator would be an unbroken arc of an ellipse.

(*b*) Notice the large dark patches which give the appearance of the "man in the moon" when seen without optical aid; these are still known as "seas," although no water occurs in them. Look at the more or less circular cavities well visible on the surface when the moon is about a week old; these are "lunar craters," and their appearance is much the same as that of large volcanic craters viewed from above. When the moon is a little more than Half Full, look near the terminator in the northern hemisphere (if you use an astronomical telescope, this will be the lower hemisphere in the field of view), and a long range of mountains—the lunar Apennines—will be seen.

(*c*) Notice the dark shadows on the sides of the large objects observable on the moon; they are directed towards the terminator, and are shadows thrown by the sun. The sharpness of the shadows shows that the moon has no appreciable atmosphere.

Telescopic appearance of the moon.—The darker parts of the illuminated surface of the moon, as seen by the naked eye or with a small telescope, were considered by observers of two or

three hundred years ago to be seas, while they took the bright parts to be land. But the so-called seas, when examined by telescope of 3 or 4 inches in diameter, appear to be broken up by various streaks and peaks, and do not exhibit continuous surfaces such as they would do if they consisted of water (Fig. 255).

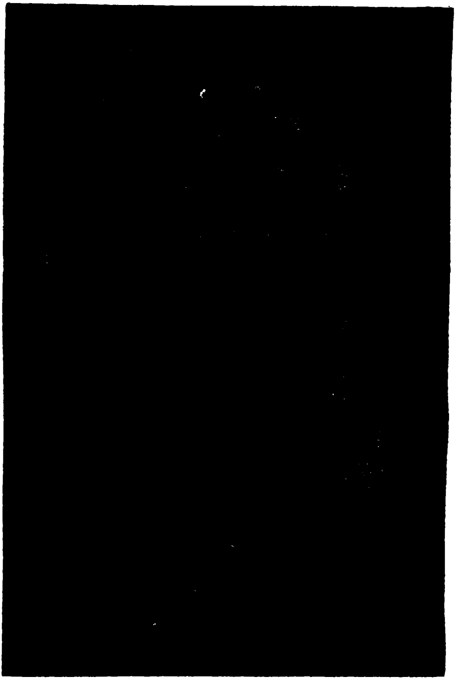


FIG. 255.—Photograph showing some characteristic formations on the surface of the moon.

Lunar formations may be grouped into five classes:

1. *Craters* more or less like the mouths of terrestrial volcanoes in appearance.

2. *Plains*, which are the seas of early astronomers.

3. *Mountain formations* similar to mountain ranges on the earth.

4. *Rills and clefts*, often running like deep trenches for many miles through plains and mountains.

5. *Ray-systems*, or bright-coloured streaks, which spread out from some of the craters, and give much the same appearance as the top of a peeled orange.

Craters on the moon.—These craters vary in size between very wide limits. Some are so small that they can scarcely be distinguished, even with a large telescope; while others have diameters of as much as fifty, or in some few cases a hundred, miles. Each consists of a circular rampart, or ring of rock, rising to a considerable height above the level of the surrounding lunar country, and generally one or more conical peaks are to be found within the enclosed area. Lunar craters are thus very large compared with terrestrial ones.

The moon has no atmosphere.—If there were water on the moon there would necessarily be an atmosphere of water vapour. The absence of any sort of appreciable atmosphere is indicated by the following observations:

1. The well-defined character of all shadows upon the lunar surface. They are invariably free from blurred edges.

2. The *sudden* disappearance of a star when the moon comes between it and the earth.

3. The edge of the moon is as bright and sharp as other parts of its disc; whereas, if there were a lunar atmosphere, it would be dim and hazy.

Temperature of the moon.—Every place upon the moon is illuminated for fourteen days, and in darkness for the same period. During this "fortnightly" day the sun's rays tend to make the rocks of the lunar surface very hot; but, on account of the absence of an atmosphere, the heat is radiated into space almost as fast as it is received. Even during this long day the temperature of the sun-lit portion of the moon is probably not higher than the freezing-point of water, and during the fourteen days of darkness it must fall two or three hundred degrees below zero.

CHIEF POINTS OF CHAPTER XXIX.

The phases of the moon are due to the fact that the moon is a non-luminous body illuminated by the sun, and the bright part is seen in different aspects in the course of the moon's monthly revolution around the earth.

A lunation, or synodic month, is the period from one New Moon or Full Moon to the next; its length is 29½ days.

A sidereal month is the period taken for the moon to pass completely round the celestial sphere; its length is 27⅓ days.

The moon moves among the stars in a path close to the apparent annual path of the sun; on this account it rises, souths, and sets, on the average, 50 minutes later every day.

Earth-shine is light received by the earth from the sun, and some of it being reflected to the moon, illuminates slightly the whole disc of that body turned towards the earth. This produces the phenomenon of "the old moon in the young one's arms" near the time of New Moon.

The New Moon is invisible; what is usually called New Moon is the moon three or four days old.

A crescent moon cannot be seen far from the sun, and the horns are always pointed away from the sun. In the evening they point towards the east, in the morning towards the west.

Harvest Moon is the Full Moon nearest the autumnal equinox, and *Hunter's Moon* is the following Full Moon. When they occur the daily rotardation of the moon is less than at any other time of the year.

Eclipses of the moon are caused by the moon being wholly or partially obscured by the earth's shadow; they occur at Full Moon, and may be total or partial.

Eclipses of the sun are caused by the moon coming between the earth and the sun; they are of three kinds, (1) total, (2) partial, (3) annular, and always occur at New Moon.

The moon's orbit.—The moon travels round the earth in a nearly circular orbit, which it takes 27⅓ days to traverse. When the moon is at its nearest point to the earth in the course of its revolution it is said to be in *perigee*; when it is at that point of the orbit most removed from the earth it is said to be in *apogee*.

Physical features of the moon.—The extensive dark patches known to early observers as seas and oceans, have been proved by closer telescopic study to be broken up like other parts of the lunar surface, though not to the same extent. The various lunar formations may be classified into (*a*) craters, (*b*) plains, (*c*) mountain ranges, (*d*) rills and clefts, (*e*) rays, or bright coloured streaks.

The absence of an appreciable lunar atmosphere is indicated by (*a*) the well-defined character of shadows upon the moon, (*b*) the sharpness of the edge of the moon when seen with a telescope, (*c*) the sudden disappearance of a star when the moon comes between it and the earth, (*d*) no clouds are ever seen upon the moon.

EXERCISES ON CHAPTER XXIX.

1. (*a*) State the relative positions of the sun, moon, and earth during an eclipse of the sun and during an eclipse of the moon. (*b*) Why is there not an eclipse whenever there is Full Moon?

2. Write what you know about the moon.

3. Draw diagrams showing the position of the moon in its third quarter, and for an eclipse of the moon.

4. State what is meant by the "phases of the moon," and explain the cause of them. Draw a diagram showing the relative positions of the sun, moon, and earth at New Moon and Full Moon.

5. Explain and illustrate by a diagram (*a*) the phases of the moon, or (*b*) the succession of the four seasons, or (*c*) the variation in the length of day and night.

6. Give notes of a lesson on an eclipse of the moon.

7. A novelist describes a ploughman as returning home from work by the light of a *rising* crescent moon. Explain why this is improbable. Draw a diagram—looking from the north—to show the positions of sun, earth, and crescent moon the ploughman actually sees.

8. Describe how you could determine the length of a lunation and of a sidereal month. State the length of each.

9. Explain the reference to the direction of the horns of the moon in the following lines:

> "O Lady Moon, your horns point towards the east:
> Shine, be increased:
> O Lady Moon, your horns point towards the west;
> Wane, be at rest."

10. Would it be possible for an eclipse of the moon to be seen at a place during the daytime? Give reasons for your answer.

11. At about what time does the moon rise at the end of the First Quarter, and at Full Moon?

12. Does the moon rise every day of the month? If so, why is it not visible every day?

13. At what phase in a lunation is there the greatest difference between the times of rising, southing, and setting of the moon and sun?

14. What evidence can you bring forward to justify the conclusion that the moon revolves around the earth nearly in the plane of the ecliptic?

15. The motion of the moon among the stars is a *real* motion, and that of the sun is an *apparent* motion. Explain the difference between the two movements.

16. A well-known novelist describes a party as stumbling through darkness for an hour during an eclipse of the sun. Comment upon this statement.

17. In a certain work of fiction an eclipse of the sun is described as having occurred the day after Full Moon. What have you to say to this statement?

18. The battle of Crécy was fought on Aug. 26, 1346 A.D., about a week after New Moon. A "fearful eclipse" is reported by some historians to have occurred on the morning of the battle. Show the impossibility of this being a real eclipse either of the sun or moon.

19. A total eclipse of the sun is recorded in the *Anglo-Saxon Chronicle* as having occurred on Oct. 29, 879 A.D. Astronomical calculations show that no solar eclipse occurred, but there was a total eclipse a year earlier on Oct. 29, 878 A.D. Explain whether you would prefer to believe the *Chronicle* or the calculations.

20. The next total eclipse of the sun will occur on May 17, 1901. On what day in May will there be a New Moon, and about what date will the succeeding Full Moon occur?

21. In giving particulars concerning an eclipse of the sun, the district over which the eclipse will be visible, or the longitude or latitude, are stated. No particulars of this kind are, however, given for an eclipse of the moon. Why should there be this difference?

22. Can there be an annular eclipse of the moon? Give reasons for your answer.

23. Vespucius, observing in the torrid zone and a clear atmosphere, is said to have seen the moon to the east and west of the sun on the same day. Comment upon this statement.

24. In the year 1900, Full Moon occurred on Sept. 9. In the year 1896 Full Moon occurred on Sept. 21. In which of the two years was the Harvest Moon best observed?

25. In what direction would you look for Full Moon shortly after sunset?

26. Artists sometimes depict a star near the concave side of a crescent moon. Explain why this is incorrect.

27. Comment upon the lines:

> "The moon's an arrant thief,
> And her pale fire she snatches from the sun."
>
> *Timon of Athens*, IV. iii.

28. Explain why it would be impossible to see the moon and stars as described in the following extract from a recent work of fiction: "The moon, which was in its First Quarter, was still low down in the east, but the stars were thick overhead."

CHAPTER XXX.

MOTIONS OF PLANETS.

111. CHARACTERISTIC MOVEMENTS OF PLANETS.

i. **Observation of apparent motions of planets.**—Find from *Whitaker's Almanack* or a similar publication whether one of the planets Mars, Jupiter, or Saturn is visible. If so, look in the position given for the planet, which will look like a star, but will not twinkle so much as an ordinary star. Observe the position of the planet with reference to the stars near it. Make the observation whenever possible for several nights extending over so long a period as possible. You will find that the planet's position with reference to the stars varies from week to week.

ii. **Morning and evening stars.**—Find from a calendar when the planet Venus is an "evening star." Look for the planet in the western sky shortly after sunset (Fig. 256). Notice its position with

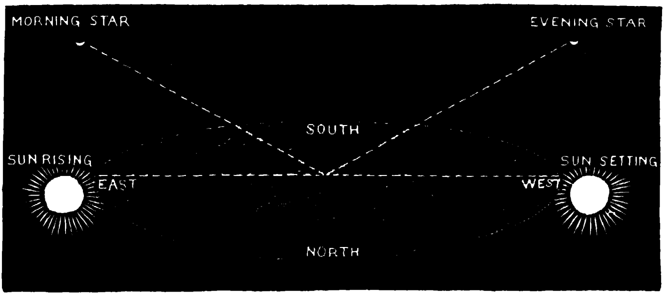


FIG. 256.—Morning and evening stars.

reference to the sun. Repeat the observation on as many occasions as possible. You will find that Venus gets nearer, or farther, from the sun day after day. In the latter case, notice that the planet reaches a maximum distance, but afterwards the distance between it and the sun diminishes day by day. After a while Venus is too near the sun to be seen at sunset. A few weeks afterwards it can

be seen as a "morning star," rising before the sun, and after it has reached a maximum distance from the sun it will swing back as the days go on. These changes can be understood by arranging a lamp, globe, and ball to represent the positions of the earth and Venus with reference to the sun, as in Fig. 257.

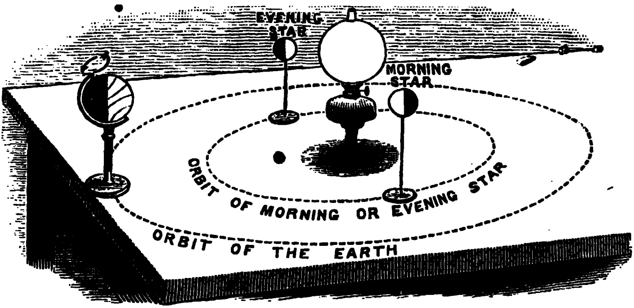


FIG. 257.—Experiment to explain the appearance of morning and evening stars.

iii. **Determination of a planet's apparent path.**—Find from a calendar the Right Ascension and Declination of a planet visible at the present time. Mark this position upon chequered paper having lines corresponding to lines of Right Ascension and Declination drawn upon it (Fig. 259). Mark the positions which the planet will occupy at intervals of about a fortnight for several months. A line drawn through these points represents the apparent path of the planet.

Apparent movements of planets.—In addition to the stars which retain their relative positions night after night, bright star-like objects are often seen which shift their position in regard to neighbouring stars. Such "wanderers" upon the celestial sphere are known as "planets"—a word having precisely the same meaning. The apparent motions of all these bodies are characterised by the same peculiarities. Each moves sometimes in an eastward direction, then retires back a little, and afterwards again advances to a position in front of the previous turning point, to begin the movement afresh. Each planet changes considerably in brightness and apparent size, and, most important fact of all, all of them traverse paths which lie close to the ecliptic.

Planets are, therefore, bodies which move in the heavens like glow-worms crawling along the face of a solid, revolving vault sparkling with brilliant lights. They appear to be carried round with the firmament from east to west, and at the same time to

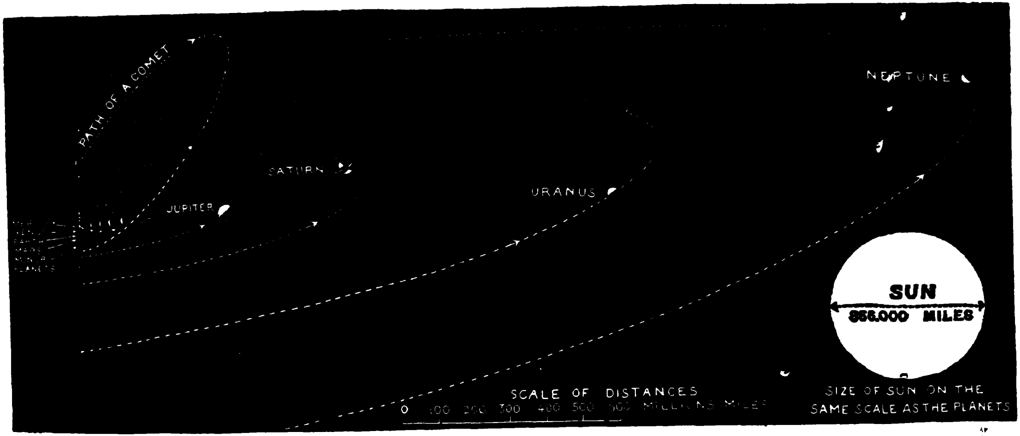


FIG. 258.—Relative distances and sizes of the sun and planets.

Planet.	Period of Rotation.	Period of Revolution.	Number of Satellites.
Mercury, - - - -	88 days. (?)	88 days.	None.
Venus, - - - - -	225 days. (?)	225 "	None.
Earth, - - - - -	23 h. 56 m. 4 s.	365·25 "	1
Mars, - - - - -	24 h. 37 m. 23 s.	1·8 years.	2
Jupiter, - - - -	9 h. 55 m.	11·86 "	5
Saturn, - - - -	10 h. 14 m. 24 s.	20·46 "	9
Uranus, - - - -	Doubtful.	64 "	4
Neptune, - - - -	Doubtful.	165 "	1

have a motion of their own. The ancients recognised five such bodies having a star-like appearance, namely, Mercury, Venus, Mars, Jupiter, and Saturn. These, with the moon, appear to travel round the heavens in almost the same path—the ecliptic—as that in which the sun apparently journeys, thus indicating that a relation exists between them all. For this reason, the sun and moon were formerly classified as planets as well as the other wanderers, though they are not referred to as such at the present time. Since the invention of the telescope two large but never very bright planets, known as Uranus and Neptune, have been discovered, and a host of smaller ones, only one of which is visible to the naked eye. The planets, with their moons, together with comets and the sun, form the *Solar System* (Fig. 258).

Explanation of apparent paths of planets.—It has been explained that the earth travels round the sun once in a year. All the planets journey round the sun in a similar way, but each has its own path and takes its own time; and, in consequence of this, the apparently complicated motions of the planets upon the celestial sphere are produced. Fig. 259 shows

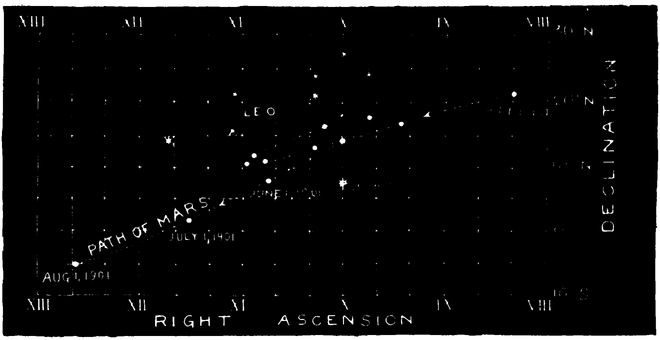


FIG. 259.—Apparent path of Mars in 1900-1901.

the apparent path of the planet Mars among the stars during the years 1900-1. It is seen that the path over which the planet appears to move is looped in a characteristic fashion, which is easily understood by a careful examination of Fig. 260, in which various positions of the earth and the planet Mars on their orbits are shown. The time of revolution of Mars round the sun is

one year ten months, as compared with one year in the case of the earth. While the earth is moving from *A* to *B* on its orbit, Mars is similarly moving from *A* to *B* on its own orbit, and the succeeding positions of the two bodies after equal intervals of time are shown by consecutive letters. The dotted lines, passing through corresponding positions of the earth and

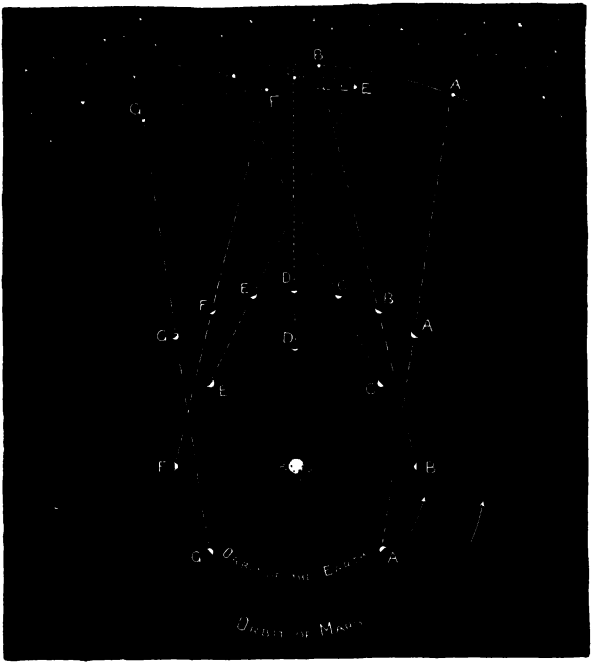


FIG. 260.—Diagram to explain the apparent looped paths of Mars and other planets.

the planet under observation, locate the apparent situation of the planet in space to a terrestrial observer, and if these localities are joined by a curve the looped path which is shown in the figure is obtained.

It should here be mentioned that when a planet or any other member of the solar system is moving *eastward* among the stars

it is said to be in *direct* motion, whereas motion towards the *west* is described as *retrograde*.

Designation of planetary positions.—A planet is said to be in *conjunction* when it is in the same direction as the sun, and so comes on the meridian at the same time; it is in *inferior conjunction* if it is between the earth and the sun, and in *superior conjunction* if on the remote side of the sun. When the earth is not only in the same straight line with the planet and the sun, but between the two, the planet crosses the meridian at midnight, and is in these circumstances said to be in *opposition*. The apparent angular distance between the position of the sun and that of a planet, as observed from the earth, is known as the *elongation* of the planet. When the elongation is ninety degrees (90°) the planet is in *quadrature*. It will be at once perceived that when the elongation is 0°, a planet is in conjunction, and when it is 180° the planet is in opposition. Only planets outside the earth's orbit, or, as they are called, *superior planets*, can be in opposition.

Morning and evening stars.—What is usually known as the "morning" and "evening" star is the planet Venus, the second planet in order of distance from the sun. The planet Mercury also appears as a morning and evening star, but it is much fainter than Venus, and can only be seen just above the sun at sunrise or sunset. When Venus is visible in the sky it is by far the brightest object in the heavens. This, because of its nearness to the sun, will, as in the case of Mercury, be for a few hours before sunrise or a few hours after sunset. If it is watched day by day, after it has just appeared as an evening star, its position seems to steadily change, becoming more and more eastward. After a time this eastward movement ceases and the planet remains stationary for a day or two. Then a westward progression is observed; the planet gets closer and closer to the sun at sunset, and is finally lost in the twilight glow. After a while, it appears on the other side of the sun, and is seen as a morning star. It moves to a maximum distance of 47° away from the sun, and then goes back to the sun again.

Venus thus appears to oscillate to and fro between 47° west and 47° east of the sun. Of course, the planet does not really swing to and fro in this way, but only seems to do so on account of its own motion and the earth's motion round the sun. Its path with reference to the stars is like that of other planets.

The appearances of Venus before sunrise and after sunset, which have given rise to the popular expressions "morning" and "evening" stars, are easily understood by placing a lamp, globe, and ball, to represent the sun, earth, and Venus, in the positions shown in Fig. 257. When Venus occupies the position in its orbit marked "morning star," the earth, as it rotates, brings an observer into such a position that he sees the planet before the sun becomes visible to him, *i.e.* before sunrise. When, on the other hand, Venus is at the other side of its orbit, it is seen after the sun has set, and is therefore an evening star. Both Mercury and Venus would be visible near the sun in the daytime if it were not for the overpowering glare of sunlight in the atmosphere.

CHIEF POINTS OF CHAPTER XXX.

Apparent motions of planets.—Seen with reference to the stars, a planet moves forward, stops, moves backwards, stops, and moves forward again, when observed for several months. These are apparent movements caused by the motion of the planet in its orbit, and the orbital motion of the earth. Motion towards the east is described as *direct* motion, and motion towards the west as *retrograde*.

Planetary aspects expressed in angles.—*Elongation* is angular distance between the position of a planet or the moon and that of the sun. At *conjunction*, the elongation = 0°; at *quadrature*, the elongation = 90°; at *opposition*, the elongation = 180°.

Morning and evening stars are the planets Venus and Mercury, both of which can only be seen shortly before sunrise or after sunset.

EXERCISES ON CHAPTER XXX.

1. Define fully (by diagram or otherwise) the meanings of the following terms:

Gibbous. Elongation. Opposition. Conjunction.

2. Describe and explain the looped path which a planet appears to traverse among the stars.

3. A bright planet was seen by a person at 11 p.m. in winter. He thought it was the planet Venus. Was he correct? Give reasons for your answer.

4. The planets Jupiter and Venus are much alike in their appearance to the naked eye. How could you tell one from the other by observing them for several weeks?

5. How would you distinguish a planet from a star?

6. Draw a diagram showing the position of the planet Venus with reference to the sun and earth, when it is an evening star.

QUEEN'S SCHOLARSHIP EXAMINATION.

DECEMBER, 1900.

ELEMENTARY SCIENCE (MEN AND WOMEN.)

Answer THREE *out of the* FIVE *questions in Section I. and* THREE *out of the* FIVE *questions in Section II.*

SECTION I.

1. You are provided with (1) a spring balance with the readings in grams, (2) a lump of stone, and (3) a vessel graduated in cubic centimetres, and large enough to hold the stone. Explain how you can use these things so as to verify the "Principle of Archimedes."

2. A small ring is laid on the middle of a round table. Three strings, supporting weights of 13 lbs., 24 lbs., and 37 lbs. respectively, are fastened to the ring, and the weights are allowed to hang over the edge of the table. It is required so to arrange the weights and strings that the ring may remain at rest. Explain the possible arrangement or arrangements (1) when the table is so smooth that friction may be neglected, (2) when friction has to be taken into account. Draw a diagram to illustrate your answer.

3. By means of an india-rubber tube the steam from a boiling kettle is passed into a mixture of ice and water in which a thermometer is placed. The experiment is continued for a considerable time, the mixture being kept well stirred. Describe the results which may be observed and the behaviour of the thermometer.

4. A person arranges a basin of water and a candle in such a way that the reflection of the candle on the water seems to him to be in the same straight line as a coin at the bottom of the water. Draw a diagram to show the necessary arrangement, and give any explanation that you think necessary.

5. About what volume of oxygen is contained in 1000 cubic centimetres of air? Describe experiments by which you could prove the truth of the statement contained in your answer.

SECTION II.

6. Some copper turnings along with a little water are placed in a corked bottle; the cork is pierced by a funnel whose stem dips into the water, and, also, by a delivery tube. Describe the results that

follow when diluted nitric acid is poured down the funnel. Explain why the gas which at first appears in the bottle is different from that which appears later on.

7. What meaning do you attach to the following equation?

$$HCl + NaHO = NaCl + H_2O.$$

If the atomic weight of oxygen = 16, that of chlorine = 35·5, and that of sodium = 23, what weights of the substances indicated by HCl and NaHO will be required to furnish 10 grams of the substance indicated by NaCl?

8. A man remarks that the stars which he sees on a September evening are not the same as those he saw at the same hour on a March evening. How far is he right and how far is he wrong as to his facts? How would you explain to him the difference between the appearance of the sky in March and in September?

9. About what time of year does the full moon reach its greatest altitude? and about what time of night? Draw a diagram to explain your answer.

10. What do you mean by an "annular" eclipse of the sun? Explain how such an eclipse is caused. Illustrate your answer by a diagram, showing the positions of the sun, earth, and moon, and also the cone of total shadow.

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